Developing a Multidisciplinary Best Practice Manufacturing Education and Research Laboratory for 21st Century Competitiveness

by

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Abstract

In the last decade both industrialists and educators have acknowledged the presence of competency gaps in graduates entering manufacturing careers. As a result, the United States is presently faced with a crippling skills shortage in the manufacturing sector that is adversely affecting relative growth of the manufacturing sector and thus the relative decline in its share of the Gross domestic product (GDP) over the years. Despite the depression and record high unemployment rates in many states, it is widely reported that manufacturers are currently finding it difficult to fill critical manufacturing jobs that are needed to meet customer delivery dates, maintain margins and plan for future expansion. Recent studies have attributed this difficulty in filling manufacturing positions to the skills gap phenomenon.

In the early in the 19^{th} century, Engineering had been taught primarily as a hands-on subject. However with advances in science, beginning in the 19^{th} century, the pedagogical emphasis in engineering education shifted more towards classroom and lecture based instruction with less emphasis placed on hands-on education. Researchers in education have shown that despite the emphasis on classroom/lecture based instruction, Engineering students ten to favor sensual, visual and active learning styles. Competency gaps have emerged due in part to incompatibilities in teaching and learning styles.

The manufacturing industry is a dynamic industry that has seen advances in Information technology (IT) and continual emergence of new technologies. These changes in manufacturing require a new breed of manufacturing engineers who are less understood by today's educators. Today's manufacturing engineer needs to be versatile and have the ability to take a systems view of the manufacturing environment. In this research we attempt to provide

answers to the questions; what are competency gaps of entry level graduates viewed from both an educator's and industry perspectives, and what methodologies need to be applied to bridge these competency gaps. As an initial step toward bridging the competency gaps in manufacturing, a meta-analysis was conducted to uncover the competencies that are considered important in the manufacturing industry. This was accomplished through an extensive literature review in addition to a manufacturing industry survey.

Once the competency gaps have been identified, there will be a need to prioritize them in order to establish what components/elements should be made part of a hands-on manufacturing laboratory, whose goal is to bridge the gap between industry needs and a manufacturing curriculum.

The objective of this research is to make a contribution towards the development of a taxonomy that could be used as a general best practice for manufacturing education. This research documents two years of experience developing a hands-on manufacturing teaching laboratory. The foundation for this research is based on the development of a realistic manufacturing environment that mimics the intricacies of a real world manufacturing environment. This was accomplished by designing and building a model factory/learning factory called Tiger Motors.

By mimicking realistic problems commonly found in a manufacturing environment, students' experiences in the lab would lead to a conceptual understanding and reinforcement of theoretical concepts taught in class. In addition, Tiger Motors provides a test bed for students to experiment and validate various theoretical concepts in a practical setting, as well as allowing students to put into practice the various manufacturing/industrial engineering tools used for designing and analyzing of manufacturing systems.

Reaching a consensus on whether the use of engineering laboratories is effective in achieving student outcomes in manufacturing education has remained a contentious topic among academia, and is subject to ongoing research.

As contribution to this cause, several interdisciplinary manufacturing labs were developed for junior, senior and graduate level instruction in industrial engineering. To evaluate the effectiveness of hands-on labs with respect to student outcomes, student surveys were conducted at the end of the semester to establish students perceptions on the value of hands-on learning. In addition, a post-only experimental design was created in which the performance of a control group was compared to the performance of a treatment group. A total of three different treatment groups received hands-on training in the lab in addition to participating in the lecture. The control groups in all cases participated in just the lecture. The hypothesis for this experimental design was that the treatment group's performance on a post test would be significantly better than that of the control group. Results indicated statistical significant differences for the overall score related to the subject matter tested, thus supporting the hypothesis that students hands-on labs do add value to student's learning.

Assembly line balancing (ALB) is one the most important problems in assembly work associated with manufacturing environments. This problem has been studied for many years with several methods and heuristics techniques being proposed. An important input to the ALB problem is the standard operation time which can be established using stopwatch time study method or any one of the many available predetermined time study methods. Predetermined time and motion studies are an alternative method for establishing standard operation times and can be used for existing or yet to be built assembly lines.

Despite the significant amount of research on ALB, little has been mentioned on what methods were used for establishing standard operation times used as input in ALB problems. It is logical that the quality of the line balancing solution can be affected by the standard operation time used. Since standard operation time used in ALB is dependent on the method

used, the research question to be addressed is what method would yield a better line balancing solution. A study of the efficacy of the method used for establishing standard operation times for use in an ALB problem was conducted. Results indicated that predetermined time study underestimated the actual time spent on an assembly task. Despite the difference in task times between the two methods, the quality of the line balancing solution seemed unaffected by the method used to establish the time standards.

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Chapter 1

Introduction

The Encyclopedia Britannica defines manufacturing as the making of products from raw materials by using manual labor or, machinery and is usually carried out systematically with division of labor. Manufacturing has been intrinsically linked to the strength of economies.

Countries with strong manufacturing sectors tend to have much stronger economies, and consequently, improved standards of living. However, with the passage of time and the advent of globalization, more and more countries are starting to embrace manufacturing as a means of strengthening their economies. As a result of this there is now a greater variety of products that consumers can choose from.

Globalization has led to open market economies, and increased competition among manufacturers resulting in a high level of competition in the manufacturing environment. Consequently, the survivability for many companies is at an all time high, especially for US companies that are faced with high operation costs as opposed to their counterparts in other parts of the world. Manufacturing has always been an evolving industry, thus the companies need to stay ahead of the curve if survivability is desired.

Manufacturing started off as craftsmanship industry in which a complete product was fashioned from a pile of raw material by individual craftsman. In the 18th Century, the industrial revolution began to take shape and in came organized manufacturing where the goal was to improve productivity. Early industrialists realized the need to fragment manufacturing into series of unskilled tasks.This was accomplished by substitution of manual operations with machines, the objective being to attain accuracy and repeatability as well as increasing productivity. This led to better quality products that were more affordable. This was the beginning of mass production. Mass production utilized the concept of material flow through a factory by standardizing operations as well as product components.

The early 20th century saw the advent of industrial engineering pioneered by consultants such as Frederic Taylor, Frank Gilbreth, and others. Taylor and compatriots created rules for measuring industrial time, and the definition of industrial productivity. After the world war Japanese scientists invited Deming to help them revolutionize the Japanese industry. Deming introduced new ideas of management including statistical process control which the Japanese fully embraced.

During this time, Toyota Motor Corporation was having difficulties with suppliers of electrical components and decided to study Ford Motor Company manufacturing with hopes of incorporating their methods. However, they found the Ford system to be too resource intensive and demanding in capital to work in Japan. Using the teaching of Deming and ideas of Taiichi Ohno and Eiji Toyoda, Toyota Motor Corporation was able evolve mass production to a new system called Lean manufacturing.

Information technology (IT) is an integral component of today's manufacturing environment. Relative to manufacturing IT encompasses a broad range of computer and communications technologies. IT includes the hardware that computes and communicates, the software that provides the data, knowledge, and information while at the same time controlling the hardware; the robots, machinery, sensors, and actuators, or effectors. Information technology can be viewed as an integrator of the application of robots and computers in manufacturing. The application of computers and robots in automation has driven the efforts of manufacturing engineers. In environments where process efficiency is a desired trait, the use of robots and computers in automated processes offers a competitive advantage. An example of a good business strategy based on automation is found in production of aluminum beverage cans. IT is used to support a number of other dimensions such as agility in manufacturing and product design response to changing consumer preferences.

Lean Manufacturing helped Japanese companies produce better quality products at more affordable prices. This new competitive edge saw Japanese companies eating into a huge share of North American market share, even forcing some European and America companies to fold. Those companies that survived have been forced to reevaluate their manufacturing principles, with many companies adopting Lean manufacturing starting in early 1980s.

In 1995, a group of industrial leaders and academics set out to answer questions on the future of manufacturing. A report entitled, *Next Generation Manufacturing, (NGM)* was published in which a framework of actions deemed necessary to be competitive in 21st manufacturing environment were identified. *Next Generation Manufacturing* report set out to identify competitive drivers in the future business environment and define attributes that would be necessary to succeed in the 21st century manufacturing business environment. The next generation manufacturing company is viewed as one that has an integrated entity of people, business process, and technology with excellent response capability. The responsiveness applies to (1) customers, (2) plant and equipment, (3) human resources, (4) global market and, (5) practices and culture. One of the recommendations of NGM was that manufacturing must be addressed as a total, dynamic system that tightly integrated people, processes, and technology (Kennedy, 2003, p. 146).

In a manufacturing environment that is changing more rapidly, it is becoming increasingly imperative for US manufacturers to provide customers with shorter lead times between orders and delivery , product conceptualization and realization, greater product customization, and higher product quality and performance while meeting more stringent environmental constraints(Manufacturing studies Board, 1995). These new demands of manufacturing has necessitated for fundamental changes in the workforce, a workforce that is more skilled and educated. Nearly two thirds of workplace jobs that will be created in the coming years will require education beyond high school (Lawless, 2000). We are in a transition period which is poorly understood by educators and you people planning to join the work force. For example, unskilled jobs are disappearing and being replaced by smart machines or a technologically savvy workforce.

While Europe, Japan, and South America have developed effective ways to produce the right type of skilled employee without a university degree, the same cannot be said of North America. While in the past it was adequate for industrial and manufacturing engineers to measure only tangible yardsticks, there has been a gradual change, with the new breed of engineers requiring the ability to measure soft values, such as knowledge, technology, and skill assets.

The importance of manufacturing education has been extensively discussed in many research studies. Traditionally many engineering schools and other technology based programs have relied to a huge extent on classroom based instruction. However, there have been countless criticisms by industrialist regarding the work readiness of many manufacturing engineering graduates entering the job market. According to the findings of a number of surveys conducted seeking industrialist perspectives on the readiness of entry level manufacturing personnel, a number of incompetences were found inherent among entry level manufacturing personnel. The findings of these surveys has led to a number of questions being asked about the relevance and ability of our manufacturing education system to respond to the dynamic nature of today's manufacturing environment.

In order for the US to maintain its global position as a manufacturing super power, there is a need to embrace a new breed of manufacturing engineer, one who is versatile, and has an understanding of the systems concept of manufacturing engineering. For this to happen, there is a need for manufacturing programs to embrace new and already proven teaching ideologies that are appropriate for engineering education. The need to close the competency gaps of engineering personnel has never been more important than it is now. Researchers have posited that manufacturing education as well as the quality of graduates coming out these programs will only improve if manufacturing programs embrace appropriate learning taxonomies that have been proposed by researchers in education as well as integrating input of industrialist.

Although research has revealed the presence of different teaching styles and learning styles, little has been done to determine the compatibility of various teaching styles of instructors to the favored learning styles of students. Some of the well-known learning styles that have been researched in education and their relevance to manufacturing education will be discussed later as part of this research. They include the Myers Briggs type indicator (MBTI), Kolbs learning style Model (KLSM), Herman Brain Dominance instrument (HBDI), and Felder-Silverman Learning Style Model. According to research, engineering students have been shown to favor learning styles that incorporate elements of hands-on training. According to Felder-Silverman Learning style model (FLSM), it has been shown that a majority of engineering instructors and academics tend to have a intuitive, verbal, deductive and sequential teaching styles while engineering students have been shown to favor sensual, visual, and active learning styles (Ssemakula, Liao, & Darin, 2010). Because of these incompatibilities between the traditional teaching styles and the favored learning styles of students in engineering, competency gaps have resulted. Hopter and Kopka (2001) reported employers felt that college graduates had competency gaps in some essential skills needed to enter the workforce. The Society of manufacturing engineering has identified some of these competency gaps by conducting repeated surveys over a number of years. The surveys revealed a number of competency gaps of new graduate students. This research is being carried out in direct response to this inadequacy to fully address the alleged competency gaps of manufacturing engineering graduates. The important question that needs to be constantly addressed is:

How manufacturing educators can implement learning activities that allow the competency gaps identified by industry to be closed.

In addition, there is a need to continuously address the misalignment of manufacturing industry requirements relating to skill-sets of entry level manufacturing personnel and manufacturing curriculum. Any revelation of a disconnect between manufacturing industry requirement and manufacturing engineering curriculum can be used as a goal , then investigation on how these competency gaps can be closed should be the primary focus of this research. Another criticism of current manufacturing education is in the disconnect that exist between parts of manufacturing curriculum. The Tayloristic approach to manufacturing education that encourages the compartmentalization of manufacturing into functions, each of which is taught in different courses, has been found to be an ineffective way of readying students for manufacturing (Domblesky, Vikram, & Rice, 2001).

In recent years, new findings in cognitive processes (Felder & Silverman, 1988; Mestre, n.d.) and behavioral psychology (Koen, 1994) have demonstrated the limits of lecture, and alternatives to augment its effectiveness have been proposed (Wankat & Oreovicz, 1993), including laboratories and cooperative learning. The recognition for the need to integrate hands-on learning activities into present manufacturing curriculums that are largely lecture oriented has seen a number of initiatives in manufacturing education. The learning Factory is one these initiatives to revitalize manufacturing education. This concept that has been implemented in a number of universities (Penn State, University of Washington, The University of Puerto Rico Mayagez) has been largely successful in affording student the opportunity to participate in practice based learning. However, despite its inherent benefits, the Learning factory concept still has its limitations. According to (Domblesky et al., 2001), one major limitation of the Learning factory is its focus on integrating design and manufacturing rather than emphasizing the integration of manufacturing principles. The Learning factory concept tends to focus on the discrete entities of a manufacturing system e.g. design and relevant manufacturing processes rather than emphasizing on systems approach with different manufacturing functions all integrated together e.g. business function, technical functions, and support functions such as Quality control.

Manufacturing teaching laboratories can provide invaluable support to theoretical courses that are necessary to give students the foundation they need in understanding the various elements and competencies desired of the manufacturing profession. In the manufacturing field, laboratories are important as they provide the physical link between taught concepts and application of various tools in the development and manufacturing of products. Laboratory exercises can serve to fill the void between theory taught in various curricula and skills and knowledge expected in industry. Since the primary aim of manufacturing education is to provide enabling skills that will help students perform their intended actions efficiently in the workplace, it is imperative that an ideal training ground for students of manufacturing engineering should entail an integrated manufacturing environment that is conceptually similar to the real factory. By providing a laboratory environment that attempts to replicate a real manufacturing environment, a smoother transition from the classroom to the workplace can be promoted.

1.1 Research Question

The general consensus among academics and industrialist is that there exists a gap regarding the skill-set that manufacturing industry desires and the content of manufacturing curriculum as the methods used to deliver the content. There is a need to bridge the gap between what manufacturing industry values and what manufacturing curriculum in general offers. This research is thus meant to provide answers to the following questions

1. What does industry consider the important competency gaps of entry level manufacturing personnel?

2. What perspectives does manufacturing industry have with regards to the content of manufacturing curriculum and associated training methods used in manufacturing curriculums?

3. Does incorporating hands-on manufacturing laboratories to support various topics that are considered to contribute to the competency gaps in manufacturing reinforce student learning and interest in the subject?

1.2 The Objectives of the Research

The objective of this research is to ultimately contribute to the development of manufacturing best practices for effective teaching of manufacturing topics. This lab is intended to provide interdisciplinary training in manufacturing where students can use the training acquired from other courses from the curriculum. The manufacturing lab is intended to provide an environment where students work in teams to find solutions to manufacturing related problems as well as investigate particular concepts and validate theoretical findings through hands-on learning. A good example that would be investigated in this research is that of assembly line balancing. While the traditional classroom approach to this problem is to provide students with data to the problem as well as other pertinent information to enable the student to successfully solve the problem, the problem itself is far from the reality found in industry. The goal of this research is thus to attempt to establish the value of solving more realistic manufacturing related problems with regards to instilling confidence on the part of the student with the hope of closing the alleged competency gaps.

A number of manufacturing related labs will be developed with the goal of testing the main Hypothesis (H1) :

Reinforcing particular topics in the manufacturing curriculum with hands-on laboratory exercises increases student learning and interest in the subject

In order to test the hypothesis the following manufacturing related labs were be developed and used as the test bed of this research:

- Assembly line balancing
- Lean Values stream mapping
- Setup reductions Single minute Exchange of Dies
- Pull strategies for shop floor Control and Cell Design

Chapter 2

Literature Review

Classification of Manufacturing Manufacturing can be classified as either primary, secondary or tertiary. Primary industries are those that cultivate and exploit natural resources, such as agriculture and mining. Secondary industries are those that convert outputs of primary industry into products. Tertiary industry constitutes of the service sector such as banking, communications, health, medical etc. Manufacturing belongs to the secondary industry. Manufacturing can further be divided into discrete manufacturing and continuous manufacturing. Continuous manufacturing is when production equipment is exclusively used for a given product and the output of the product is uninterrupted. Good examples of continuous manufacturing is found in the manufacture of pharmaceuticals , chemicals, petroleum, beverages etc. On the other hand, discrete manufacturing produces individual products and includes such industries as automobiles, aircraft, appliances, machinery (Grover, 2008) etc. This project is concerned with operations of discrete manufacturing in manufacturing education. Certain manufacturing operations are required to convert raw material. Processing and assembly operations are the two basic operations used for producing finished products. Processing operations transform a work material from one to a more advanced state closer to the desired state or product while assembly operations join two or more components to form a new entity. While the processing and assembly operations are the basic transformation operations required for the manufacture of a product, additional factory operations are required if the product is meeting the desired goals of: (1) High product quality and performance, (2) On time delivery, (3) Greater product customization. The ability of a manufacturing organization to meet these goals is largely dependent on the skills of their workforce in use of more advanced technologies, greater use of information technology to reduce waste and defects, and more flexible manufacturing styles. Only when the combined skills of the workforce, advanced technologies and flexible management styles are appropriately applied to manufacturing support activities such as material handling, inspection and testing, factory coordination and control can US manufacturing remain competitive in face of growing global competition.

2.1 State of Manufacturing in North America:

The three largest manufacturing industries today are : (1)food products, (2) computers and electronic products, (3) and chemicals. Automobiles and auto parts have since dropped from third to fourth between 2002 and 2007, and fabricated metal products slipped from fourth to fifth during the same time.

Manufacturing is the engine that drives American prosperity. It is central to the economic security and national security of any country. Federal Reserve Chair Ben Bernanke stated on February 28, 2007, "I would say that our economy needs machines, new factories and new buildings and so forth in order for us to have a strong and growing economy.Mark Zandi, chief economist at Moody's Economy.com calculates that 20.5 percent of the manufactured goods bought in American in 2005 were imported. This was up from 11.7 percent in 1992 and 20 percent in 2004.

Manufacturing supports state economies and is a vital part of the economies of most states, even in those areas where manufacturing has declined as a portion of the Gross State Product (GSP). As a share of GSP, manufacturing is among the three largest private-industry sectors in all but ten states. Manufacturing remains the largest sector in ten states and in the Midwest region as a whole. It is the second largest in nine states, and the third largest in 21 others.

Manufacturing's share of State Output

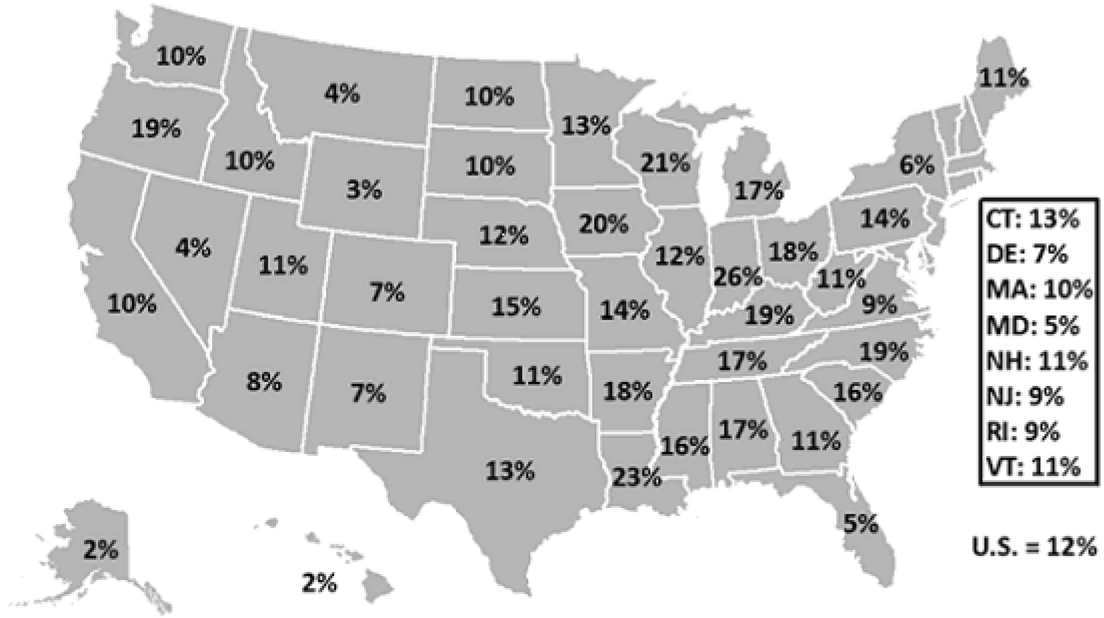


Figure 2.1: Manufacturing output by state

To give an example of the impact manufacturing has on state economies, an analysis of manufacturing in Connecticut reveals that more than half of the top 100 companies headquartered in Connecticut are manufacturing firms. Nearly 5,300 Connecticut manufacturing firms combined directly employ almost 200,000 workers and generate $11.1 billion in wages and salaries, and produce over $20 billion of the gross state product. Each new manufacturing position creates between 1.2 and 5 additional jobs in the state, and manufacturers purchase over $10 billion per year in goods and services from other Connecticut businesses. It's clear from those numbers that the health of Connecticut's entire economy is inextricably linked to the well-being of the state's manufacturing industry.

A key competitiveness factor for manufacturers is access to a skilled workforce. Manufacturers say they value Connecticut as a business location for its supply of skilled workers. However, they are also finding it increasingly difficult to fill many positions requiring advanced manufacturing skills. In addition, many manufacturers in that state have expressed concern in the quantity and quality of job candidates interested in pursuing career opportunities in manufacturing.

2.2 Scope of Manufacturing in the World:

First, manufacturing has moved from localized operations to global manufacturing primarily due to the advances in digital, communication, transportation and other technologies. It has also occurred due to the unprecedented developments and growth in educating the manufacturing workforce in places where manufacturing was insignificant only 20 years back. Global manufacturing is also driven by the arrival of new entrepreneurs in many parts of the world. Equipped with world-class infrastructure for finance, marketing and other areas, a capable workforce, and forward looking governmental organizations, the new entrepreneurs have come up to take control of global manufacturing and exploit new markets. The growth in global manufacturing is also the result of the never-ending search to pay the least for the manufacturing workers. Over the last two decades, manufacturing organizations in the developed countries have used low cost labor as a means to justify moving manufacturing operations to global destinations.

The growth in the global manufacturing workforce is yet another cause for the current transformation. With the emergence of a new political order in many parts of the world since the 1950s, countries that are large and small have invested a sizable share of their national resources to educating an engineering workforce. Starting with Taiwan and Korea in the 1950s, and more recently followed by China, India and the others, these countries have built up their educational infrastructure to produce a large number of engineering graduates capable of supporting the competency requirements of global manufacturing operations. The educational systems in those countries do not limit themselves to developing a technological workforce; instead they are preparing world-class entrepreneurs, capable of managing and challenging the established global order in business, finance and other sectors of the economy. There has been an unprecedented commitment to education that is found at both the individual and collective levels. Those commitments have helped develop and promote education from the primary to the tertiary level. Although initiated in the beginning as a means to attain higher standards of living, today the drive is to attain excellence in industrial and economic development. One cannot, and should not ignore the fact that the drive in many countries is not limited to developing a workforce to meet the current skills requirements of the industry, but to develop their tertiary education and become a strong force in research and innovation.

2.3 Perspectives of manufacturing education in the USA

A number of colleges in the USA have initiated programs to reinforce manufacturing education with hands-on laboratories in an attempt to close the competency gaps of manufacturing engineering students. The motivation behind the development of various instructional labs and learning factories found in several universities and colleges has been triggered by industry criticism that engineering students are entering the workforce with significant competency gaps which has necessitated remedial action on the part of the employer. Much of the focus has centered on competency gaps related to design experiences, while similar concerns have been echoed with respect to manufacturing related skills.

Various efforts have been undertaken to address the problem of engineering and technology graduates lacking key industry skills. The Society of Manufacturing engineers has funded some of these efforts through its initiative called Manufacturing education plan launched in 1997. In addition, the National Science Foundation (NSF) as well as other funding agencies have been involved in addressing these concerns. The learning factory (LF) was one major outcome of NSF funding attempt to address some the competency gaps that were found to exist in manufacturing education. The objective of the learning factory was to create an integrated practice-based curriculum that balances analytical and theoretical knowledge with physical facilities for product realization in an industrial like setting (Ssemakula et al., 2010, p. 3). The original learning factory was developed jointly by Pennsylvania State University (PSU), University of Washington (UW), and University of Puerto Rico-Mayaguez in collaboration with Sandia National Laboratories.

The objectives of the Learning factory were to develop were to create a practice-based engineering curriculum which balances analytical and theoretical knowledge with manufacturing, design business realities, and professional skills. Learning factories at each partner institution were to be integrally coupled to the curriculum for hands-on experience in design, manufacturing, and product realization, as well as a strong collaboration with industry, outreach to other academic institution, government and industry. The Learning factory concept proved quite successful in participating institutions, supporting a number of new courses such as: (1) Product dissection (2) Concurrent Engineering (3) Technology based Entrepreneurship (4), Process Quality engineering as well as other interdisciplinary design projects. These new courses were built around existing courses which were modified to take advantage of the new facilities made possible by the Learning factory. The implementation also involved partnership with local industries at each institution, with local industries contributing significant resources in terms funds, staff, equipment, and internships. Although the learning factory is not easily adaptable due to its large size and cost associated with its implementation, it does provide some insights into how practice based manufacturing curriculum can be developed and implemented. One example of the adaption of the Learning factory can be found at Wayne State University. Using the same concept as that of the leaning factory, Wayne State University developed and implemented a number of hands-on laboratory activities that supported a targeted number of courses around a unifying theme of designing and making a model engine. Using this approach, students were able to generate drawings of engine components and use the drawing in developing process plans and actually fabricating the components. Finally the components were assembled into a working model engine. Each of the activities are part of an appropriate course in the curriculum, with those activities coordinated between the courses. The advantage of this approach is that students take different courses all of which are linked to one particular functional product that students actually make in the laboratory. Using this approach, students are able to see the whole picture of an integrated manufacturing system at work, as opposed to the tayloristic approach of compartmentalizing manufacturing along functional lines and teaching specific functions in separate courses (Domblesky et al., 2001, p. 2). Traditionally manufacturing education can be viewed as Tayloristic in its approach, which consequently does not help students connect how the activities taught in the different courses relate and fit together within a manufacturing enterprise.

The Learning factory and its adaptations thus provide a means of overcoming this inadequacy of the lack of integration between learning concepts and courses. The experiential hands-on approach using a common product in multiple courses, gives students a good understanding of the range of issues involved in design, planning, fabrication, assembly, and testing of a functional product. Using an integrated project of this nature exposes students to all processes involved as well as providing motivation and a sense of accomplishment and satisfaction. In an attempt to close the competency gaps in manufacturing education, a number of universities and colleges in the USA have launched initiatives that incorporate practice based manufacturing activities to reinforce lecture based learning. This has been done by developing manufacturing based laboratory activities. Among the popular practice based curriculum initiatives has been the development of Computer Integrated Manufacturing laboratories (CIM). While the goal for most institutions has been to attain computer integrated manufacturing status, it has to be understood that a significant effort in terms of resources and commitment is required to attain such a status. It would seem that a number of institutions surveyed followed a common progression in the development of CIM. It would appear that this progression was from (1) stand alone machines, (2) islands of automation (3) flexible manufacturing system, and (4) integrated manufacturing systems. In some cases the labs developed were used to support a number of unrelated courses. For instance (Macedo, Colvin, & Colvin, 2005) describes the development of a 10 week course in machine vision as part of the automation course, while (Shiver, Needler, & Cooney, 2003) describes the development of automation course used to teach students how to interface a wide range of equipment such as programmable logic controllers (PLCS), conveyors, pneumatic actuators, control relays, hardware sensors; robots, machine vision and smart sensors. Oakland University at Rochester operates a lab called Artificial intelligence and Manufacturing laboratory (AIM)(Van Til, Sengupta, Srodawa, & Patrick, 2000). The Aim laboratory is an interdisciplinary laboratory proposed and developed by both computer science and engineering faculty. Its purpose is to facilitate issues concerned with education in automated manufacturing. It allows students to learn about how people are integrated in a modern manufacturing environment through their involvement in team based projects. Two major systems found in this laboratory are the intelligent manufacturing cell and intelligent factory. Equipment found in the intelligent cell in CNC lathe, CNC mill, robotic manipulator, PC based cell controller and PC based computer aided design/Computer aided manufacturing (CAD/CAM) system. The intelligent factory consists of an automated storage and retrieval system (ASRS), simulated manufacturing cells, computer controlled transportation system, programmable logic controllers, and a factory controller. It is important to note that the intelligent factory operated in the AIM laboratory is a physical simulator of a real factory and offers the opportunity to identify constraints which are otherwise not recognizable by a simulation model. The availability of physical simulation in conjunction with computer simulation enhances the learning environment.

Arizona State University (ASU), the lead award winner in 1990 has spent some time developing an identifiable CIM curriculum (Koelsch, 1990). This program was built as a response to industry needs in Arizona and is focused on multidisciplinary research centers.

In discussing how academia can better provide the education for manufacturing leaders, Leo Hanifin of Renselear Polytechnic Institute (RPI) defines better to mean more students focusing on manufacturing with more realistic experiences, and with greater emphasis on people issues in manufacturing(Hanifin, 1991) .

Based on the analysis of various manufacturing programs benchmarked, it is apparent that there exists significant amounts of diversity in the implementation of hands-on manufacturing laboratories in academia. It is apparent the various manufacturing laboratories in many of the institutions were developed without a common roadmap.

2.4 Methods used in teaching/modeling manufacturing systems:

Omurtag discussed the need to find a medium between theory intensive and laboratory intensive extremes that constitute the domain of manufacturing education (Ormutag, 1987). Designers and developers of manufacturing systems education have a plethora of manufacturing modeling techniques that range from very abstract to real. Figure 2.2 shows the work of Benjamin and Smith that depicts the different modeling techniques available that can be used for teaching various concepts in association with manufacturing (Benjamin & Smith, 1990; Borchelt & Alpetiin, 1990)

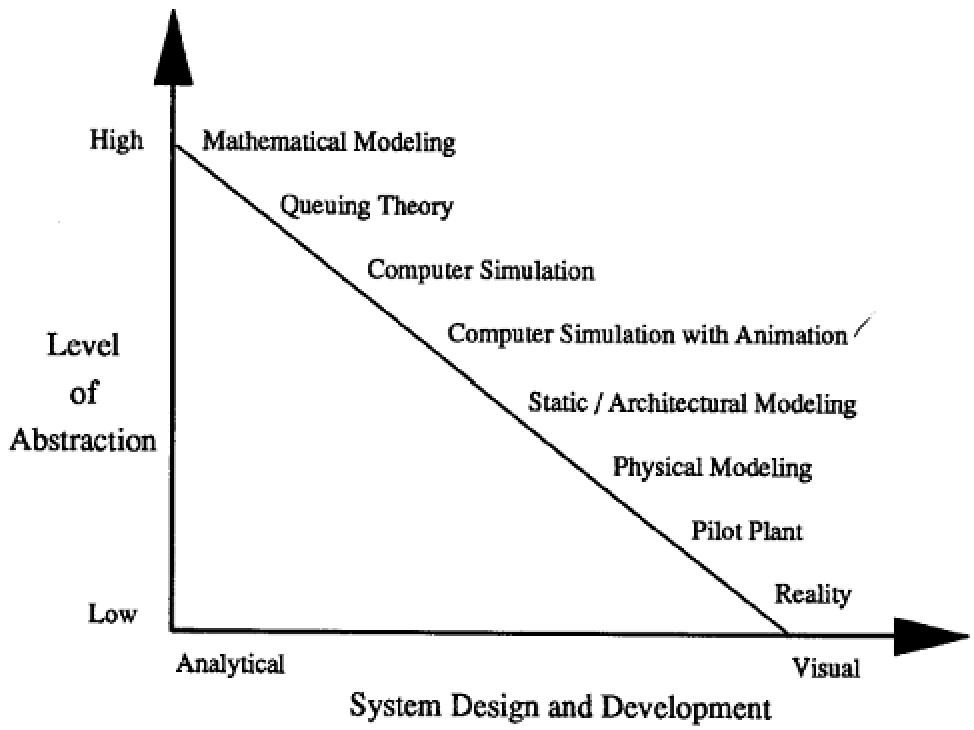


Figure 2.2: Manufacturing modeling techniques

It is important for designers of manufacturing education to be fully aware of these modeling techniques and to know how each can be effectively applied to teach various concepts in manufacturing education. It may be argued that each element/topic in manufacturing education can be effectively taught using any of the methods depicted in Figure 1. The research question that can be asked is:

- What modelling technique should be applied to a particular manufacturing topic for effective learning to occur

2.5 The need to revamp Manufacturing education in the US:

2.5.1 America's aging workforce:

Americas graying workforce will soon affect the USAs manufacturing industry. According to a recent report from the Center for Workforce Success (National Association of Manufactures & Manufacturing Institute of Deloitte and Touche, 2003), it is reported more than 76 million baby boomers will retire over the next 20 years, with only 46 million generation-Xers taking their places. This may lead to shortage of skills in the manufacturing industry. Currently the US has been forced to rely heavily on skilled immigrant workers to fill the shortfall of skilled workers in the manufacturing industry. This need for skilled workers is projected to increase by 10 million by 2020. Even during the recession when employers had to lay off many workers, employers still reported a shortage of highly skilled, technically competent employees who could fully exploit the potential of new technologies and support increased product complexity (National Association of Manufactures, 2001). This development is not helped by the inherent lack of interest among the next generation of America's workforce to pursue careers in manufacturing industry. The Manufacturing Institute and Deloitte and Touch recently conducted two major research studies that revealed negative student perceptions about careers in manufacturing. With near unanimity, respondents across the country saw manufacturing opportunities to be in stark conflict with the characteristics they so desired in their careers and as a result, many of these youths had no plans or envisaged themselves pursuing careers in manufacturing in the coming future (National Association of Manufactures & Manufacturing Institute of Deloitte and Touche, 2003).

2.5.2 Projected growth of manufacturing:

Most positively, the looming retirement of baby boomers is not all that will necessitate the hiring of additional manufacturing employees. After weathering a particularly harsh recession and very slow recovery, many Connecticut manufacturers say they will need to add employees because of favorable business prospects. A substantial 79 % of manufacturers responding to the survey indicated they would need more employees in the next five years because of the development of new products, increases in their sales or the expansion of their companies. About 23% said they would need to replace 25% or more of their employees within the next five years.

2.6 Manufacturing jobs that are in demand:

What types of skilled workers does the US need to fill current and future shortages of skilled employees in manufacturing? A number of surveys have been conducted by different economic regions of the US to determine the skills shortage in the US. In one such survey conducted on manufacturers in Connecticut to establish the current and long-term demand for specific types of manufacturing positions , Connecticut manufacturers were asked about their current skills shortages as well as their projected needs in 2008 and in 2011. The survey sought employers perceptions regarding skills shortage in 12 different job categories outlined in the list below.

Assuming that results of the survey of Connecticut manufactures are a realistic representation of the entire country, the following sectors were found to have the most critical needs for skilled workers:

1. Tool and die makers
2. CNC programmers
3. CNC machinists
4. Engineers
5. CAD/CAM workers
6. Technical sales staff
7. Plant Managers
8. Production Managers
9. Technical trainers

10. Research and development staff

Among those positions identified by manufacturers as extremely difficult to fill were CNC programmers and CNC machinists (27% each), tool and die makers (22%), technicians (21%), and machinists (20%). Engineering positions were described as extremely difficult to fill by 10%, and very difficult to fill by another 37%.

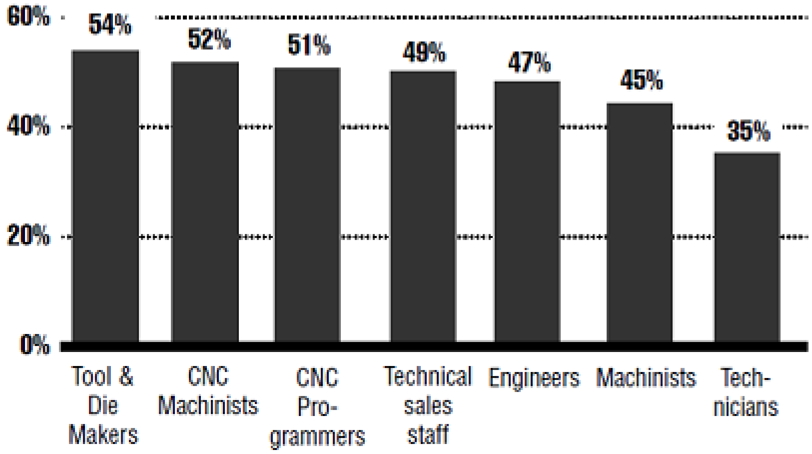


Figure 2.3: Difficulty to fill positions in manufacturing

Among a number of reasons manufacturers found some jobs in Figure 2.3 difficult to fill were:

1. lack of necessary skills for the given position

2. Applicants were found not ready to enter the job market for a variety of reasons

2.7 Manufacturing skills sought by Manufacturers:

Through surveys, the skills that manufacturers seek in employees were established (see Figure 2.4). the skill areas most frequently identified as current needs were, team building/problem solving, lean manufacturing, equipment operation, blueprint reading, and engineering. Projecting ahead five years, employers said the skills that will be most needed are lean manufacturing, equipment operation and engineering, team building/problem solving.

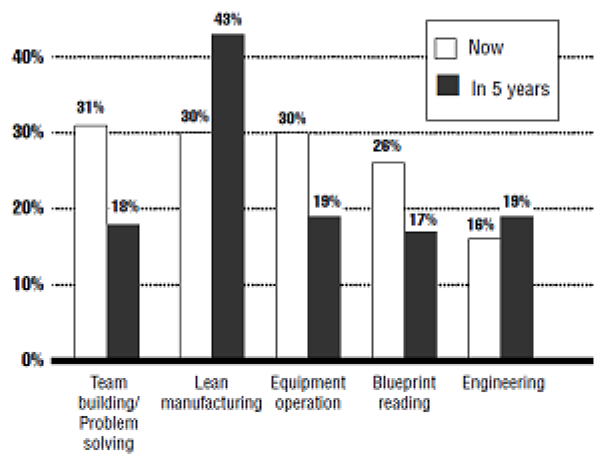


Figure 2.4: Manufacturing skills sought

2.8 Worldwide programs to improve Manufacturing:

Endeavors to enhance manufacturing activities in various parts of the world have seen the emergence of country specific, regional, and international efforts to strengthen the manufacturing education. While new educational and training programs in manufacturing are developed, existing programs are revised and updated. Special programs are being created to address the needs of advances in technologies, and unique arrangements are being made for on-the job education in areas where such arrangements are appropriate. While these efforts are helping to address some of the demands of manufacturing, there are continuing challenges in meeting the needs of the changing manufacturing world.

This segment of this project reports the efforts of two major international entities, namely the Society of Manufacturing Engineers (SME) in the USA and the Intelligent Manufacturing Systems (IMS) in Europe in preparing the manufacturing engineering workforce. SME serves more than half a million manufacturing engineers, executives and professional members in about 70 countries around the globe. SME also serves as the source for knowledge, networking and skills development for aspiring manufacturing engineers and other related careers. SME has also been the agency responsible for developing and helping implement the criteria for accreditation of the collegiate level manufacturing engineering and technology programs.

SME initiated a process in 1985 to study the skills and competencies needed in the manufacturing industry and develop curricular models for implementation by academic institutions. The process expanded in scope and operation over a ten year period to the point that in 1994, a series of workshops organized by the Education Committee of SME produced a formal document entitled Curricula 2002 that included recommendations for curricular contents for the manufacturing engineering and manufacturing engineering technology degree programs at the baccalaureate and masters level. The recommendations of Curricula 2002 have not only been the basis for many of the manufacturing programs established since 1995, they have also served as the foundation for establishing the criteria used for accrediting manufacturing engineering and technology programs.

In 2008, SME initiated a review of the recommendations of Curricula 2002 and a study of the skills and competencies needed for the long term growth of the manufacturing industry. The process started with the First Manufacturing Education Leadership Forum in Pittsburgh, PA in June 2008. A diverse group of invited guests representing academia, industry, and government met to assess the need for continuing development, upgrading, and updating of manufacturing education programs. The workshop recommendations are currently being compiled for publication as Curricula 2015 document. Since it was a work-in-progress document, it was expected to take its final shape after SMEs Manufacturing Education conference that was conducted in June 2009 in Austin, Texas. Some of the recommendations reached included the following key components of the manufacturing degree programs :

a. Technological Competencies - Product Realization Process Engineering Materials

- Engineering Mechanics and Design
- Manufacturing Processes
- Manufacturing Systems Design, Analysis, and Control
- Control of Machines
- Quality Systems
- Computer Systems
- Electrical Circuits and Electronics

b. Professional Competencies

- Communication
- Global Multiculturalism
- Teamwork
- Ethics
- Creativity and Innovation
- Enterprise Management

- Manufacturing Information Systems
- Product Life Cycle Management
- Enterprise Resource Management
- Financial Management
- Human Resource Management and Supervision
- Entrepreneurship
- Intellectual Property Rights

c. Mathematics and Science Competencies

- Mathematics
- Physics
- Chemistry
- Bioscience

2.9 Psychology of Learning:

While acknowledging the various competency gaps identified in manufacturing education, and the methods proposed in order to close these competency gaps, there is also a need to examine the behavioral issues that affect manufacturing education. Students have to go through the system, and it is imperative that not only the curriculum have the right content, but the manner in which the curriculum is delivered to the students goes a long way in determining the readiness of manufacturing graduates to meet the needs of industry. The process of curriculum development is irrelevant without a discussion on the needs of the primary customer, the student in this particular case (Erevelles, 1992, p. 33). A manufacturing curriculum should be designed in such a manner that students learning is enhanced. This leads us to ask the question: what is learning? And how can it be determined that learning has indeed occurred. Learning is a difficult phenomena to define, let alone measure.Merriam-Websters dictionary defines the word teach to mean the following: to cause to know a subject; to show how; to make to know the disagreeable consequences of an action; to guide studies of and to impart knowledge (Merriam-Webster, 1989).

Educators need to understand that an innate level of learning takes place in a number of ways. Simply telling students something does not mean they will understand complex theoretical or social phenomena (Mumford, 1993). Facts and theories are dry, one dimensional and will not take seed unless they are put into context, brought to life and practiced. Theory supported by practice makes understanding, and hence learning, far more likely (Meredith & Burkle, 2008).

It is common knowledge that individuals are unique, in the sense that what interests one individual does not necessarily interest the other. Despite these differences amongst individuals, the variations of behavior between individuals are known to be quite consistent and orderly. This has prompted psychological scientists like Myers and McCauley, 1985 to develop psychological classification method, the Myers Briggs type indicator (MBTI). The MBTI can be used to identify learning preferences by plotting four bipolar personality traits which may be combined to yield sixteen different personality traits. Among the different indices found that are part of MBTI indices include: Extroverted or Introverted (EI) index, Sensing (SN) index, thinking personality (TF) index, and Judgment process index (JP). A good explanation of these indices is found in (Myers & McCaulley, 1985). MBTI can thus be used to develop teaching methods to address the different personalities of students and also to understand and accept type differences in learning styles. A good understanding of MBTI can be useful in developing different motivational techniques for different learning styles. (Ssemakula et al., 2010), suggested that traditional learning based on lectures favored by engineering academics tends to produce graduates with limited real world hands-on experience favored by industry. While acknowledging the different learning styles of individuals, it is important that a manufacturing curricula be designed so as to strike the right balance between the different learning styles of individuals. (Lamancusa, Jorgensen, Zayas-Castro, & Ratner, 1995) determined that a majority of engineering students favored more visual and tactile learning styles. In order to enrich the learning experience, the instructor must be prepared to develop a portfolio that would stimulate, and be of interest to various personality types. Discussions on the use MBTI in adapting teaching styles to learning styles have been carried out in a number of research studies (Rosati, Russel, & Rodman, 1988).

Acknowledging the different learning styles is one step in a series of steps required for developing an effective learning environment. There is also the additional need for educators to agree on what would consist of learning objectives for a particular subject matter. Blooms taxonomy is a classification of learning objectives proposed in 1956 by a committee of educators chaired by Benjamin Bloom. Blooms taxonomy classified learning objectives into 3 different domains: Cognitive, Affective, and Psychomotor. The fulfillment of these objectives follows a hierarchy of needs policy, implying that learning at higher level is dependent on having attained prerequisite skills and knowledge at a lower level. A goal of bloom taxonomy is for educators to focus on all three domains, creating a more holistic form of education (Anderson & Krathwohl, 2001). At higher domains, mental processing results in greater understanding of the subject matter. Thus the question that needs to be addressed is:

In which category would traditional classroom based lectures fall into?

Traditional classroom based lectures require low level processing on the part of the students, while it is anticipated that laboratory exercises can be used to reinforce classroom material. Laboratory exercises designed for manufacturing education would require the highest level of processing. To complement Blooms taxonomy, other research activities support Blooms theory. In Figure 2.5, the depiction shows the cone of learning, tailoring manufacturing curriculum to include hands-on manufacturing activities which may lead to enhanced learning, thus fulfilling the objective of preparing preparing the graduate for immediate usefulness in the workplace.

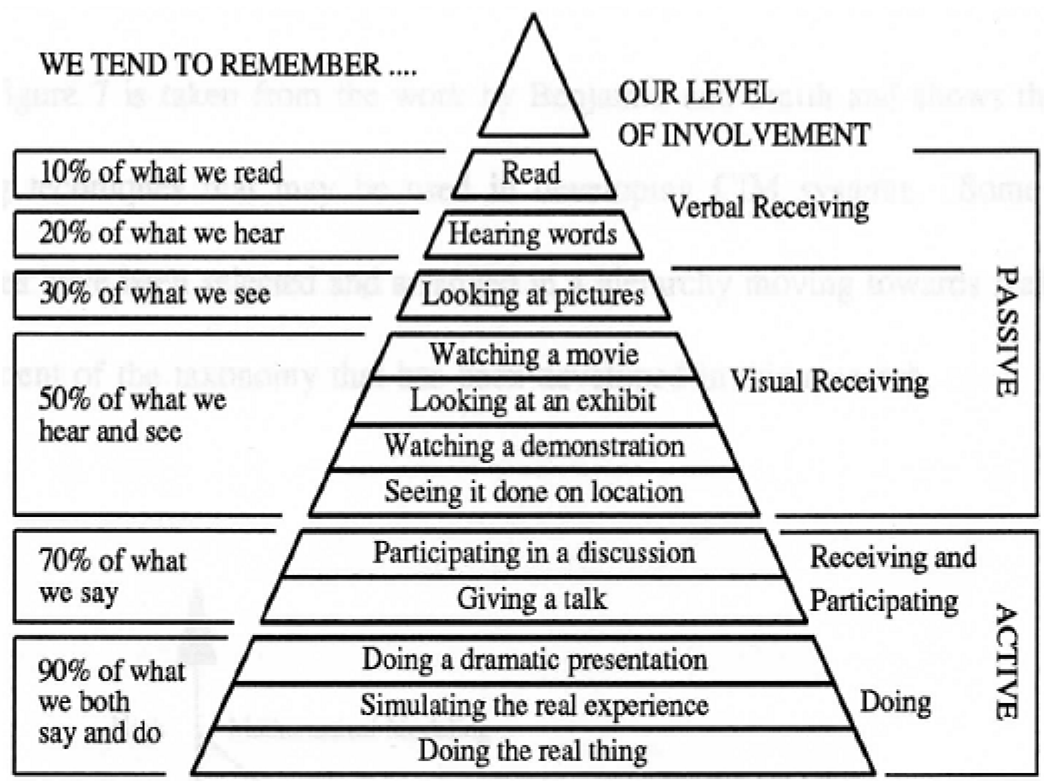


Figure 2.5: Cone of learning

2.10 Problem Based Learning:

2.10.1 Learning through Simulation Games:

The development of the manufacturing Lab at Auburn University is intended to support a number of manufacturing related courses by providing a hands-on learning environment. The lab is intended to provide an integrated manufacturing environment. Figure 2.6 below illustrates the interaction of courses intended to be supported by the manufacturing systems lab:

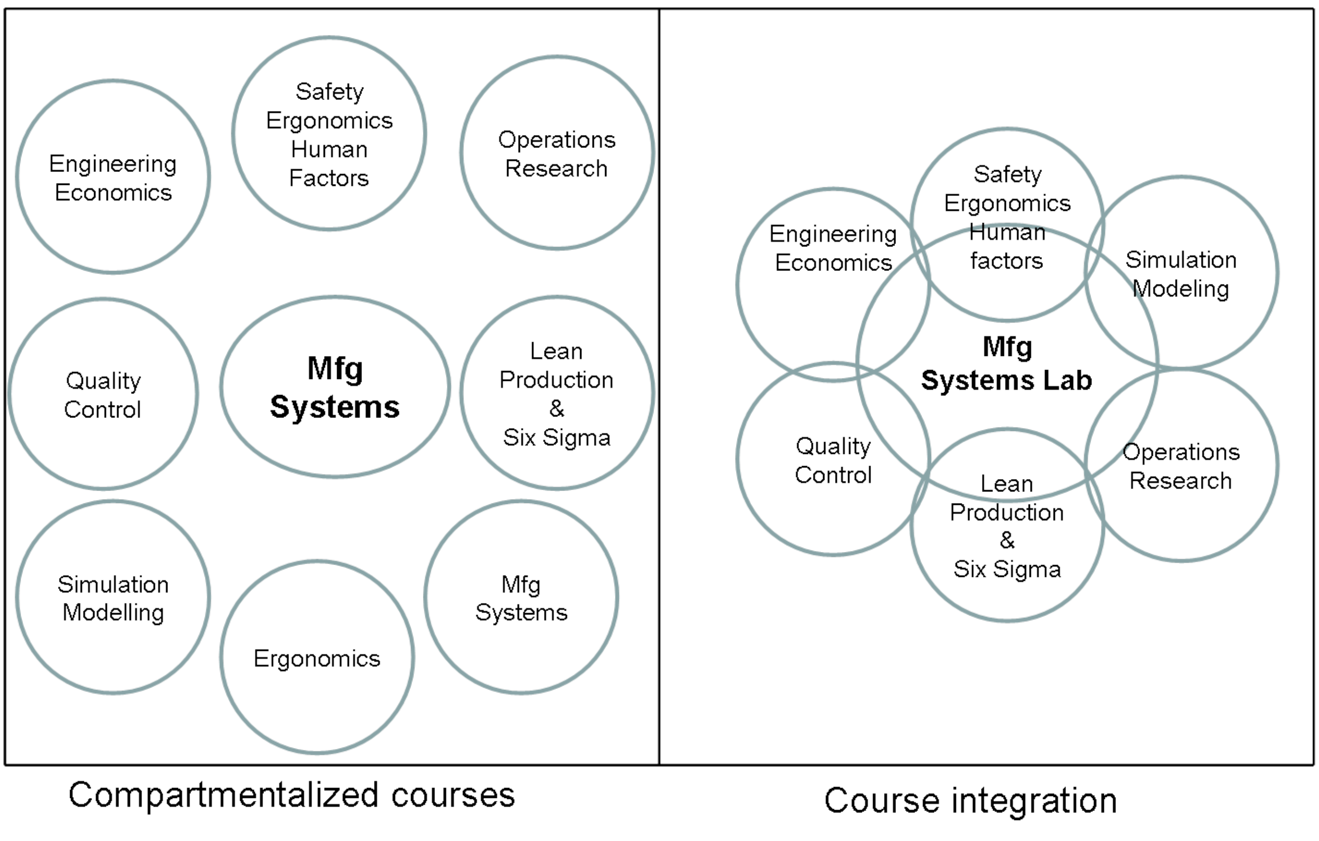


Figure 2.6: Interdisciplinary course integration

However the focus of this dissertation is related to the problem based learning activities intended to support mainly manufacturing systems courses (INSY 3800) and Lean Production (INSY 5800/6800). The Lean production and manufacturing systems courses have been taught at Auburn University for a number of years. The courses have been centered on traditional classroom based lecture. In line with the objective of closing the competency gaps of entry level manufacturing personnel in Engineering, it is envisaged that incorporating problem based learning to supplement the lecture based material will enhance students knowledge and interest in the subject matter. Some scholars have posited that Problem based learning not only helps stimulate interest in a subject matter, but also promotes knowledge transfer and long term retention as (Riis, 1995). However, this point still remains contentious as reviewed in (Gijbels, Dochy, Van Den Bossche, & Segers, 2005) and (Prince, 2004).

The focus of problem based learning is to provide an experience that affords participants a sense that they are engaged in a real problem situation, in which case learning becomes a natural byproduct of their engagement and motivation to solve a problem. (Brown & Duguid, 2000) pp 136) points out that people learn in response to a need. When people cannot see the need for what is being taught, they ignore it, reject it or fail to assimilate it in any meaningful way, hence the motivation behind hands-on learning activities. PBL is can be a valuable approach to learning how to implement and practice lean manufacturing because all cultural values that are the cornerstone of lean manufacturing can be practiced. Because the underlying practices of Lean manufacturing differ from the traditional western cultural values that focus on individual achievement, independence, emphasis on short term goals and so on (Holfstede, 1991), it is important to foster a culture that encourages lean social dynamics. Therefore to be successful in lean manufacturing it is important to not only emphasize the hard factors (Industrial Engineering tools for process improvement), but it is absolutely necessary that the so called soft factors that are so vital for process improvement be embraced.

The combination of the hard factors and soft factors has seen Toyota continue to outperform its competitors. Not only does PBM help students acquire knowledge about a particular subject matter, but it also creates an environment where students acquire skills in an experiential way in addition to helping them to learn about themselves and others that are part of the group (Badurdeen, Marksberry, Hall, & Gregory, 2009, p. 3). Therefore Lean Manufacturing education requires that there be training in both soft and hard skills in both the social/cultural and technical aspects. PBL is thus a valuable tool for learning how to implement and practice lean because it embraces the concept of teamwork.

The value of PBL has prompted a number of scholars to develop a large number of hands-on simulations used for teaching lean manufacturing concepts in academia and in Industry. A comprehensive list of simulation games developed for lean manufacturing training can be found in (Badurdeen et al., 2009, p. 6). Practitioners of lean manufacturing acknowledge that a successful and sustained lean manufacturing transformation requires the transformation of an organization's culture, and this has been by far the largest factor that contributed to failure of sustained lean initiatives in most companies. In recent years the use of computers in simulating a lean manufacturing environment has increasingly been used (Feinstein, Mann, & Corsun, 2002). However the effectiveness of computer based simulation for lean education is limited due to the inability of the technology to facilitate the right kinds of realistic interactivity and collaborations between members.

2.10.2 Use of Simulation and Games in Manufacturing education:

Simulation and gaming has been a valuable tool for training purposes in both industry and institutions of learning. A meta-analysis of simulation and games in manufacturing revealed that 75% had a production line focus, meaning that they mainly emphasize the application of lean tools to improve material flow with only a few focusing on enterprise wide operations, which implies that other functional areas that support manufacturing such as logistics and distributions, ergonomics and safety are often ignored (Badurdeen et al., 2009). It would appear that the majority of the Lean simulation and games were developed for large volume, discrete product manufacturing.

The study also revealed that the most demonstrated lean tools were cell design and layout, line balancing, pull production and one piece flow, Kanban, quality at the source, standardized work, value stream mapping, cross training, set up reduction, 5S and visual control. Most of the lean simulation games that have been developed for training purposes usually involve multiple iterations, in which a conventional push system is transformed into a pull production. In some cases, lean simulation games involve a single team of participants working through a number of iterations to transform a process by applying lean tools, while in other cases multiple teams work parallel and competing with each other. In some cases of lean simulation and games, the developers have encouraged that participants to these games be divided based on their learning styles e.g. Kolbs Model. Kolbs learning theory sets out four distinct learning styles (or preferences) which are based on a four stage learning cycle). His theory offers us a way to understand individual people's learning styles and also an explanation of the cycle of experiential learning that applies to us all.

2.10.3 A review of manufacturing teaching labs in US colleges

A review of manufacturing labs in some of the top colleges in the US was done. Sahin, 2006 carried out a survey to benchmark manufacturing labs across US colleges. The top Industrial Engineering and Manufacturing programs were selected to be benchmarked. A summary of Sahin's finding is given in Figure and it shows that the major focus in labs was in manufacturing automation and manufacturing control. A number of these colleges had some form of Computer integrated manufacturing lab in place, in which the use of Robots, automated material handling and in a few cases the used of radio frequency identification technologies were explored (University of Arkansas, Eastern Illinois University). The use of Computer numerical controlled machines was popular among many of the programs surveyed. Rapid prototyping was another common feature among many of manufacturing labs. It was interesting to note that only a handful of programs benchmarked had labs that focused on lean manufacturing system or production related manufacturing concepts.

However, further review of literature and Internet search did reveal some programs that did have a production focus. Rochester Institute of Technology maintains a lab called ”Toyota production systems lab”. This lab is supported by Toyota Motor Engineering. The emphasis in the lab is placed on concepts of team work, problem solving by studying fundamental behavior of production lines. Further review of Lean manufacturing training revealed significant number of organizations that offer lean manufacturing related training. Badurdeen et al.,2009, gives a good overview of a number of physical simulation games that have been developed over the years to provide lean manufacturing related training. Again, only a handful of colleges programs appear to offer these type of hands-on type of activities as permanent part of their curriculum. Fang, Cook, and Hauser (2007) developed a Lean Lego lab for training students on lean manufacturing concepts. Other similar initiatives were found with University of Kentucky (Veebot simulation, ciruit board simulation), and University of Dayton (Pipe factory simulation).

	DEPT		Categoris of Manufacturng elements						
College	Industrial and Systems	Mechanical	Business Functions	Lean Mfg Six Sigma	Product Design	Information Decision support	Manufacturing Control	Manufacturing Process Automation	Manufacturing Planning
Georgia Institute of technogy labs	√				√	√	√	√	
North Carolina State University labs			√	√	√	√		√	√
Oklahoma State Univesity Labs								√	
Purdue University Labs							√		
Robert Morris University labs							√	√	
University of Arkansa Labs							√	√	
University of Central Florida Labs						√		V	
University of Detroit Mercy Labs					V		V	V	
University of Louisville Labs					V			V	
University of Texas at San Antonio Labs							V	V	
Leigh University								√	√

Figure 2.7: Manufacturing labs bench marking in US colleges

2.11 Methods used for assessing effectiveness of learning:

A significant challenge associated with introducing learning methodologies is measuring the impact on student's learning. This ability to evaluate the effectiveness of a new learning methodology is key to deciding whether the new learning methodology can be retained as well deciding whether this method can adopted as new best practice for engineering education. Despite the difficulties associated with measuring the value of hands-on manufacturing laboratories, a number of research studies have been designed to evaluate the effectiveness of new learning methods that have been developed while other research is ongoing. In this section, a discussion on some of these methods will be made as well as their relevance to the development of the manufacturing teaching lab at Auburn University.

2.11.1 Concept Mapping:

Concept maps are a procedure that is used to measure the structure and organization of an individual's knowledge (Novak & Gowin, 1984; Ruiz-Primo, Schultz, & Shavelson, 1997; Stoddart, Abram, Gasper, & Canady, 2000). Concept mapping was originally developed by Novak and the members of his research group as a means of representing frameworks for the interrelationships between concepts (Novak & Gowin, 1984; Stewart, Van Kirk,& Rowel, 1979). Concept mapping is part of a broad family of graphic organizing tools that includes mind mapping, (Buzan & Buzan, 2000) spider diagramming and other related approaches (D. Hay & Kinchin, 2008). A concept map is a hierarchical set of concept labels all linked together, with big and inclusive ideas placed at the top, with exemplary and subordinate ideas below. The concept-mapping method facilitates quick and easy measurement of student knowledge-change so that teachers can identify the parts of the curriculum that are being understood and those that are not. This is possible even among very large student groups. The concept mapping method can be taught in 20 minutes and studies have shown that an additional 30 to 40 minutes can be sufficient to make satisfactory maps of most topics. The construction of effective concept maps has been thoroughly reviewed by (J. D Novak & Canas, 2006). Concept mapping is an application that can be used in different fields, and more recently it has been used in mechanical engineering and environmental engineering (Moreira & Greca, 1996; Muryanto, 2005, 2006). For example, Muryanto explored the use of concept maps as learning tool in chemical engineering (Muryanto & Hadi, 2005). The concept mapping tool has made possible new studies of human learning in any context. For example, Otto Silesky, a principal of a secondary school in Costa Rica, sought to apply concept mapping tool in all subject in all grades(Novak. D, 2010, p. 24).

2.11.2 Matching:

When random assignment is not possible researchers undertake studies that involve control and treatment groups without random assignment. A good example of such a study was completed by Merino and Abel(2003). They compared the effect of computer tutorials (treatment) on learning to that of lecture style tutorials (Control). In this approach demographic information e.g. Grade point average, declared major are used as basis for assigning individuals to groups. This demographic data is then used to demonstrate that the two groups share similar characteristics on what is believed to be relevant variables. As a result of this, any performance differences can be attributed to the intervention.

2.11.3 Baseline Data:

If for whatever reason, it proves difficult to have treatment and control groups, then baseline data can be used as basis for analysis. Baseline data are collected to represent the status quo before an intervention is done. Depending on the nature of the research, this data could be taken from participants currently enrolled in the study or from a totally different set of subjects. For example, Kashy et al compared student grade distribution in physics for scientists and engineers at Michigan State University before and after computer assisted personalized approach (CAPA) was implemented. Baseline data can also be used in conjunction with self report survey, which can be used as further evidence to support the findings from the baseline data.

2.11.4 Post-test only:

When a pretest is not possible then a post-test design is an option. A study by Ogot, Elliot, and Glumac (Ogot, Elliot, & Glumac, 2003) provides an illustration of how this type of study can be implemented. When post-test only design is used, random assignment to the treatment or control group becomes an important factor. By randomly assigning the subjects to a treatment and control group, factors such as self-selection are eliminated as an influence to the outcome. Additionally triangulation can be used to explain the validity of the conclusion drawn from the results.

2.12 Strategies for Enhancing the Role of Manufacturing Education

The future of manufacturing will depend upon the bold steps taken to prepare a competent workforce and a new generation of entrepreneurs. In the context of global manufacturing, the manufacturing professionals must be prepared not only to seek jobs in established businesses, but to create jobs by establishing new manufacturing businesses. Entrepreneurship must become part of the educational process for the future manufacturing professionals. Furthermore, the efforts to prepare the workforce should place an increasing emphasis on student learning over teaching. The traditional educational process has emphasized the teaching methods as the primary means to prepare a competent workforce. Future efforts toward the development of manufacturing professionals must break the traditional barriers in creating educational opportunities, utilizing the advances in digital and communication technologies and delivering programs all over the world. Manufacturing education must be made available to anyone interested in it, anywhere in the world and at any time they like to learn. Extensive collaboration among the leading educational institutions and industry in a given country or around the world must become part of the means to prepare the future manufacturing workforce. Organizations such as SME, IMS and others should become agents of change and enable extensive global academic and industry collaboration, ongoing changes in curricular content to address the needs of industry, emphasis on learning over teaching, programs to develop a new generation entrepreneurs, and provisions for access to manufacturing education at anytime and anywhere. Beyond preparing a competent workforce through the educational process outlined, the agents of changage must assume the responsibilities of educating the public on the scope and the prospects of manufacturing in the future. They must also become the leading proponents to shape the policies of the governments at all levels.

We believe that a new educational experience is needed to teach the methods and technologies required for 21^{st} century competitiveness.This dissertation addresses new developments in the teaching of manufacturing needed to bridge the competency gaps of manufacturing engineering students of the 21^{st} century.

Chapter 3

Design and Development of a Model Learning Manufacturing Lab at Aubunrn University (AU)

This dissertation discusses the design and development of a new age 21st century teaching manufacturing lab intended to bridge the alleged competency gaps of entry level manufacturing graduates. The development of this lab is an attempt to prove that hands-on education in manufacturing should be made an integral component of the curricula if substantial value to students learning is to occur. In this dissertation we will discuss the design and implementation of specific lab modules deemed important to manufacturing education. In order to assess the value of the introduced hands-on learning modules to students learning, two student surveys were conducted to establish students' perception with respect to hands-on learning activities related to two courses. The details of the students surveys are discussed in section 4.8 and section 5.7.3. In addition to students' surveys, a post only experimental design where treatment and control groups were subjected to different learning experiences was used to assess the effect of various hands-on labs on conceptual understanding of course topics 5.8. The findings of this research are related to the work carried at Auburn University's Industrial and Systems Engineering manufacturing lab (Tiger Motors), however, we are hopeful that the results will shed light on how hands-on curricula can be integrated into manufacturing that is largely dependent on the lecture with positive results. In this chapter we will discuss the proposed development and implementation of the teaching manufacturing lab at Auburn University. It is important to note the elements of this lab have taken into consideration significant findings from prior research from various programs put in place in manufacturing education in the past decade. The availability of literature surveyed has helped the author gain perspectives on what an effective manufacturing laboratory would look like. In this section a discussion on the development of the manufacturing research lab at Auburn University's Industrial and Systems Engineering department will be given. The following diagram shows the illustration of the inputs and perspectives that may have been considered by various universities and colleges in developing manufacturing laboratories.

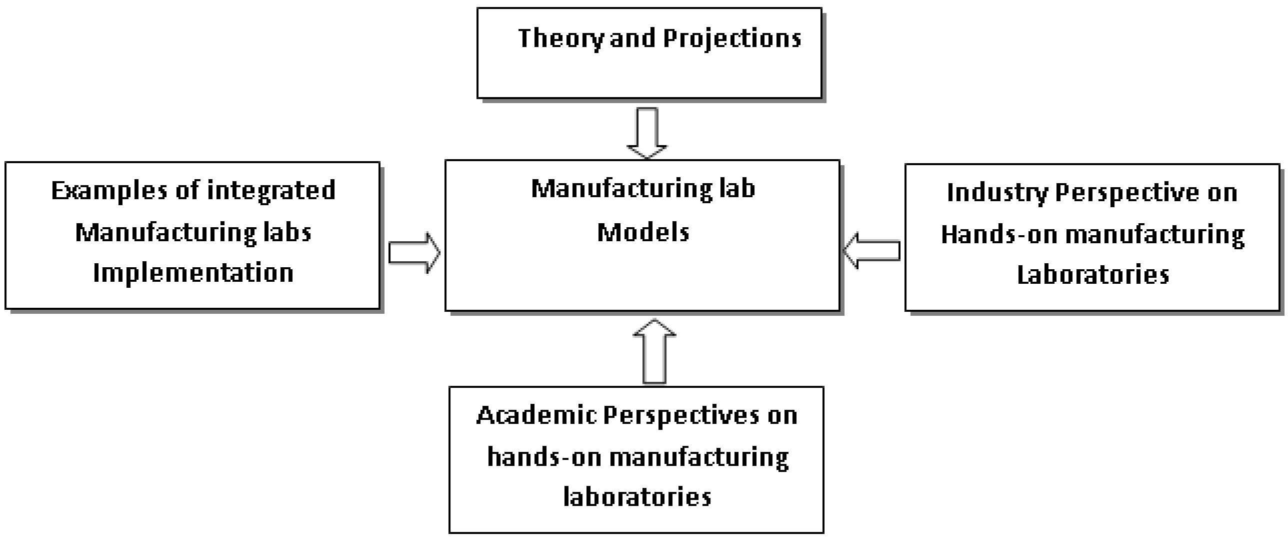


Figure 3.1: Manufacturng lab model

3.1 Tiger Motors Manufacturing Systems Design methodology

This lab was developed to teach hands-on manufacturing systems. A model car factory assembly manufacturing system was designed in a similar manner as the Learning Factory Concept (Lamancusa et al., 1995) , complete with automated material delivery system (Automated storage and retrieval system). Students are required to work in teams to solve manufacturing problems like line balancing, establishing the buffer size between stations, assignment of roles among team members, and participating in continuous improvement meeting, among many other tasks necessary for efficient running of a model factory. Because of the limited laboratory time available for students to solve large problems, students were, in some cases, presented with problems that were incompletely solved. The students were then tasked with solving the problem using the tools presented to them in the lecture. Equipment and hardware for this lab were selected to demonstrate material replenishment strategies, material handling, manual and automated assembly, Inspection, Ergonomics and Safety, Computer aided drafting/Computer aided manufacturing. By seeking academic perspectives on manufacturing education (Erevelles, 1992) was able to define particular elements/components that would be best learned through hands-on laboratory activities rather than through lecture alone. A decision on what elements/components to include in an effective manufacturing education laboratory can be best initiated by reviewing the Computer and Automated Systems Association's Computer integrated manufacturing CASA/CIM wheel, which represents a comprehensive list of important components of a manufacturing enterprise shown in Figure 3.2 CASA/CIM Wheel. Considering the complexity of manufacturing enterprise as seen in the CIM, selecting elements/components that lend themselves well to hands-on learning is no trivial matter.

3.2 Academic Perspective of competency gaps and alignment with industry requirements:

Based on earlier discussions, it is apparent that there is diversity in the manner hands-on manufacturing labs are developed to support manufacturing education, and how they have been implemented in the various programs studied. It is apparent that there is a lack of a common road map in the way the various manufacturing labs in different institutions have been implemented. The scope and content of manufacturing based curriculum tend to vary wildly, leading to my belief that programs in manufacturing stand to gain considerably if a consensus on the content and scope of effective manufacturing educational labs is found. Such a consensus would be considerably be useful in developing a set of guidelines and benchmarks for any manufacturing programs. Efforts to develop such guidelines have been made in the past, with a number of researchers offering insights on how this can be

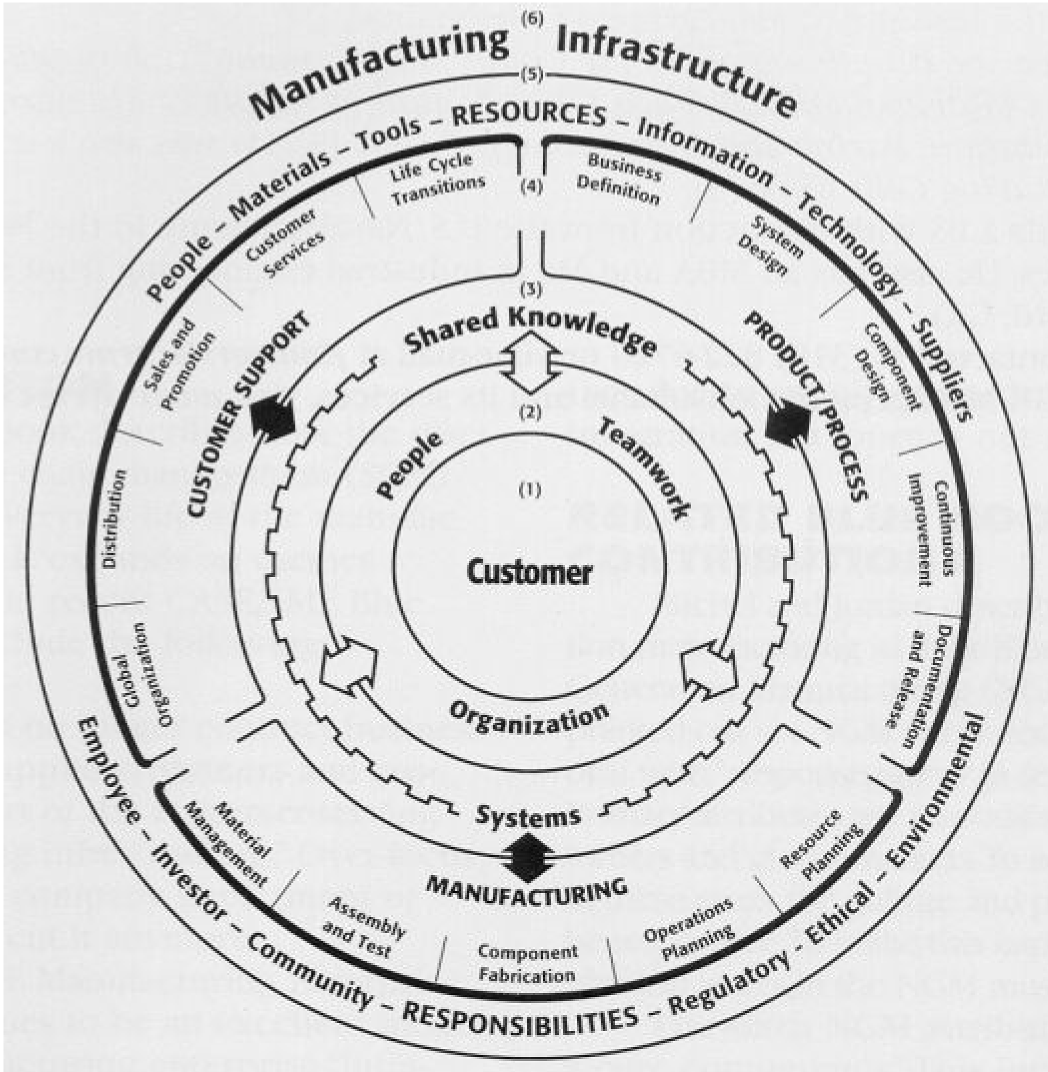


Figure 3.2: CASA/CIM wheel

done. Erevelles developed a taxonomy for developing a Computer Integrated Manufacturing (CIM) Laboratory after consulting with academics in the field of CIM (Erevelles, 1992). His work is being used as the foundation for this research. As a first step for developing an integrated manufacturing laboratory to support manufacturing education, there is a need to identify an exhaustive list of elements, subsystems, and manufacturing process technologies that may be considered potential candidates for inclusion in a hands-on manufacturing laboratory. The list of elements considered for this research has taken into consideration the list of CIM elements outlined by Erevelles in addition to other manufacturing related topics derived from areas such as lean manufacturing, Six Sigma business practice, Ergonomics and Safety. Many programs in manufacturing utilize stand-alone courses prior to senior design projects or senior capstone courses. In most cases these prior courses utilize stand-alone laboratories. The tools learned in stand-alone topics tend to be limited to textbook problems or projects that are limited in scope. As a result, students have difficulties when there is a need to apply the tools in an integrated environment even though they may have excelled in using the tools in the individual courses. In order to develop a new manufacturing lab or to develop an assessment tool that can be used to evaluate an already existing laboratory, as well as attain an understanding of intended learning objectives and experience to be provided by the various laboratories, there is a need to devise a list of elements, subsystems and associated manufacturing technologies that are a vital component of any viable manufacturing organization. A comprehensive list of elements for consideration for inclusion in practice based curriculum is given on the next page. It has to be acknowledged that this list is significantly long and unpractical as it would be impossible to incorporate most of elements into a manufacturing curriculum.

3.3 Comprehensive list of elements considered for hands-on learning activities in a manufacturing lab

Table 3.1: Business Functions

1.	Marketing
2.	Demand forecasting
3.	Project Management Skills
4.	Business Knowledge skills
5.	Written and Oral Communication
6.	Team work/Working effectively with others
7.	Customer billing
8.	Payroll
9.	Accounting Finance
10.	Cost Accounting
11.	Engineering economic analysis
12.	Documenting procedures
13.	Distribution

Table 3.2: Management Philosophies

14.	Lean Manufacturing Concepts (5S, Kanban, Continuous improvement etc)
15.	Six Sigma Methodologies (DM

Table 3.3: Product Design

16.	Computer aided Design/Drafting
17.	Process Design
16.	Facility Design/Plant Layout
17.	Manufacturing Ergonomics /Human Factors/ Safety considerations in Process Design
16.	Design for manufacture
17.	Group technology

3.4 A methodology for selecting of potential elements/components to include in a hands-on manufacturing teaching lab

As a first step toward developing an effective manufacturing laboratory to support manufacturing education, it is necessary to select elements that are considered important for manufacturing education and to determine which of these elements are best learned through

Table 3.4: Information and Decision Support Systems for Factory Management

18.	Communication Networks and Protocols
19.	Radio frequency identification technology applications in Manufacturing
20.	Process simulation software
21.	Systems Integration Software
22.	Database management

Table 3.5: Manufacturing Control:

23.	Process monitoring
24.	Process control
25.	Shop floor control
26.	Computer aided inspection/Testing
27.	Diagnostics/Error Recovery

Table 3.6: Manufacturing Process Automation:

28.	Automated Material handling
29.	Automated Assembly
30.	Automated Packaging
31.	Programmable logic Controllers
32.	Direct/Distributed Numerical control
33.	Adaptive control
34.	Finishing/Coating
35.	Flexible Manufacturing Cells
36.	Foundry/Casting
37.	Plastic Injection Molding
38.	Machine Vision
39.	Metrology
40.	None Traditional machining
41.	Robotic Manufacturing in manufacturing
42.	Sensors in manufacturing
43.	Sheet Metal Fabrication

Table 3.7: Manufacturing Planning

44.	Bill of materials for processes
45.	Materials Requirements planning (MRP)
46.	Pull Production systems (Kanban)
47.	Cost Estimating
48.	Database management
49.	Computer aided process planning
50.	NC part programming
50.	Scheduling

hands-on laboratory exercises. The relative importance of each of these elements can be determined through stakeholder surveys. There are a number of stakeholders in manufacturing education, which include students, their prospective employers, and faculty of manufacturing education. Faculty members are considered designers of the education system. Thus it is important that all stakeholder requirements, with regards to the content of and scope of manufacturing education, be solicited if effective hands-on manufacturing laboratory is to be developed. . One way of soliciting stakeholder perspectives can be achieved through stakeholder surveys. As a first step in determining the important elements of a hands-on manufacturing laboratory (Erevelles, 1992)) hypothesized that the academic community would classify some of the so mentioned elements as more important in an instructional setting than other elements. To test this hypothesis, a survey was conducted to determine faculty perspectives on the content and scope of a hands-on manufacturing laboratory. A qualitative scale for determining the relative importance of each of the elements was defined in the following manner:

Necessary/Required elements: These elements are considered as the must have elements in the lab

Useful element: These are not as important but add value to the manufacturing lab by adding onto the capabilities of the lab.

Optional elements: These are lowest ranked elements in a manufacturing lab, and can be viewed as nice to have. The exclusion of any element from this list will not adversely affect the quality of instruction

Not needed: this accounts for any elements that should not be considered as part of a manufacturing lab.

However, in Erevelles' work, consideration for manufacturing employer's perspectives were not taken into account. Since manufacturers are a big stakeholder in manufacturing education, it becomes imperative that both academia and employers' perspective be sought and aligned if an effective manufacturing laboratory is to be developed. As part of this research a survey instrument has been developed to capture employers' perspectives on the subject, and the results of this survey will be compared against perspectives of academia, so as to determine the competency gaps that need to be addressed through hands-on laboratory exercises.

3.4.1 Determination of adequate teaching levels for identified elements :

An additional domain that was considered is the teaching domain. The teaching domain identifies the level of teaching that would be considered adequate for successful learning to occur for a particular element. This domain answers the following question: What teaching level Y method should be applied to element X to effectively impart learning to the students. For the purpose of this research the teaching levels are illustrated in Figure 3.3:

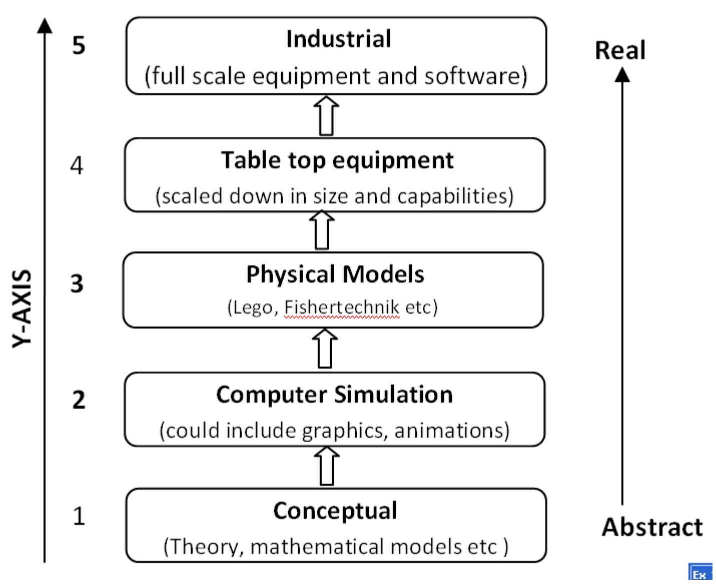


Figure 3.3: TeachingLevels

The levels depicted in Figure3.3: are used to define the minimum level at which instruction for a particular manufacturing topic can be considered effective. From the above discussion it can be noted the three steps or dimensions needed to determine the content and scope for an effective manufacturing laboratory can be illustrated in 3 dimensions as in Figure 3.4 below.

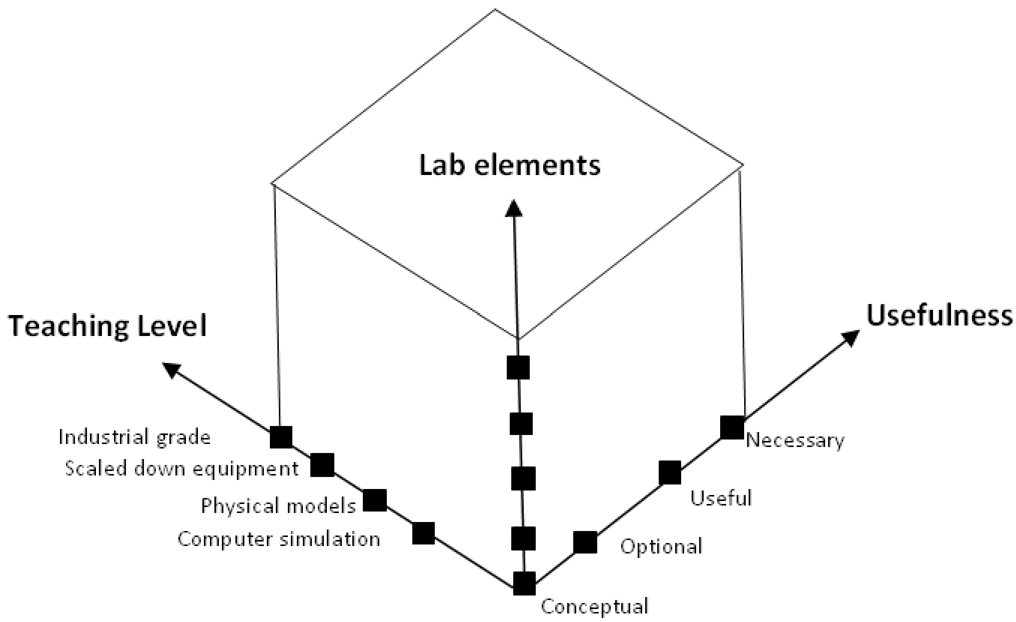


Figure 3.4: Dimensions for defining the content and scope of manufacturing hands on learning

3.4.2 A three dimensional model for establishing interdisciplinary components of manufacturing teaching lab:

In order to determine how each defined element in the manufacturing education profile fit into 3 dimensional structures shown in Figure 3.4, a stakeholder survey will be carried out. It has to be noted that this survey will only seek perspectives of manufacturing employers, taking into consideration the work done by Erevelles as he had already established the perspectives of academics with respect to CIM lab development. To compliment his work, a survey seeking the perspective of manufacturing employers will be carried out. The objective for developing this survey instrument were as follows:

3.4.3 Research Objectives for manufacturing industry perspective survey

1. This study is intended to evaluate what target skill-set manufacturing employers expect entry level manufacturing/Industrial engineers to posses. This study also seeks to expose employer's perceptions regarding areas in a manufacturing curriculum that need to be improved to better close the gap between employers desired skill-set and the educational training given to students as part of the manufacturing curriculum (Competency gaps). This study will also evaluate manufacturers current level of involvement or anticipated future involvement with emerging technologies that are predicted to be an integral component in the manufacturing.

2. Establish manufacturers' perspective on what they would consider to be important elements of a hands-on manufacturing laboratory intended to prepare undergraduates students for 21st century competitiveness.

3. Establish manufactures' perspectives on what they would consider to be appropriate level of instruction associated with each element of manufacturing profile as illustrated in Figure 3.4

4. Based on findings, develop best practice for manufacturing education for 21st century competitiveness and assessment instrument that can be used for evaluating the effectiveness of manufacturing curriculum.

3.4.4 Research Questions for the Questionnaire:

1. What level of competency in various components of manufacturing education are employers seeking in entry level manufacturing/industrial engineers

2. From a historical perspective, what are the employer's perceived inadequacies of entry level manufacturing/Industrial engineers that have required further training.

3. What does the manufacturing industry envisage as the best way for training manufacturing engineering students and what recommendations do they have regarding manufacturing curriculum

3.5 A Manufacturing industry perspective on the important elements required for manufacturing education

A survey seeking the perspectives of manufacturing industrialist on how manufacturing education curricula should be shaped in order to better prepare students for careers in the manufacturing industry was conducted. The survey was anonymous and was conducted through using an on-line survey software Qualtrics. Survey participants were invited through email to participate, as well as through an open invitation through social networking websites Linked-In. The survey sought to establish what manufacturing industry representatives considered important elements that need to be emphasized in a manufacturing curriculum. The survey was made of 20 questions composed of multiple choice, matrix, and rank order type questions. The full survey is given in appendix A.

3.5.1 Participant demographics

A total of 50 survey responses were obtained. However, only 30 participants participated fully in the survey and the results presented for this survey reflect this number. 29% of the respondents were executives while 47% were in upper management positions, and about 6% held professional positions like Quality engineer, Safety manager etc. About 35% of the respondents worked for companies involved in some form of metal fabrication (automobiles, aircraft, machine building), 6% in metal processing industry, while 53% worked for companies involved in the manufacture of other types of products. 65% of respondents' indicated working of companies involved with high volume, low variety type goods while 35% respondents' companies were low volume, high variety manufacturers. A number of responses to statements put through to participants will be discussed.

Q9:Statement 9.

In order to establish what competency gaps may exist in the manufacturing industry, participants were asked to express their perception regarding what competencies could be improved through the introduction of hands-on oriented manufacturing activities in the manufacturing curriculum. Participants were required to state their agreement with the following statement:

"Taking into account your own experience as an entry level professional and any interactions you may have had with other entry level professionals in manufacturing related jobs, please indicate your agreement with the following statement":

Introducing a hands-on approach to teaching the the given topics in a manufacturing curriculum at college level would be beneficial in addressing the competency gap in manufacturing.

Participants were given a list of potential topics relevant to manufacturing that could be introduced into the manufacturing curricula through the use of hands-on laboratory activities. Participants were asked to indicate the topics that they felt could be most beneficial in addressing the competency gaps of students.

Table 3.8: Ranking of important competencies by industry representatives

Problem solving skills	0	0	0	0	0	6	11	17	6.65
Teamwork/ work effectively with others	0	0	0	0	1	7	9	17	6.47
Written and Oral Communication	0	0	0	1	1	5	9	16	6.38
Product and Process Design	0	0	1	0	3	4	9	17	6.18
Manufacturing process Control	0	0	0	1	3	5	7	16	6.13
Manufacturing Systems knowledge	0	0	0	1	2	10	4	17	6
Quality Systems knowledge	0	0	0	1	3	9	4	17	5.94
Project Management	0	0	1	1	3	6	6	17	5.88
Specific manufacturing process Knowledge	0	0	0	1	5	6	5	17	5.88
Business knowledge/Skills	0	0	0	1	5	7	3	16	5.75
Supply Chain Management	0	1	0	2	5	6	3	17	5.41
Materials knowledge	0	0	0	5	4	4	4	17	5.41
International perspectives	0	2	3	4	5	3	0	17	4.24

Table 3.8 shows the ranked competencies by manufacturing industry representatives. it is clear that problem solving skills, teamwork as well as written and communication skills are competencies that participants felt could benefit from hands-on skills.

Q10:Statement 10

Participants were asked to rank a list of identified competencies according to how important or relevant they were to manufacturing industry. This input is important for prioritizing the order in which particular elements could be introduced or improved in any manufacturing curriculum, or used to evaluate current elements of a particular manufacturing curriculum.

Table 3.9: Desired competencies in manufacturing

Question	Least Important: 1	2	3	4	5	6	7	8	9	Most Important: 10	Total Responses	Mean
Written and and Oral Communication Skills	0	0	0	0	1	0	1	2	7	5	16	8.81
Lean Manufacturing and Six Sigma knowled	0	0	0	0	0	2	1	2	5	6	16	8.75
Product and Process Design	0	0	0	0	0	0	3	5	4	4	16	8.56
Manufacturing process control	0	0	0	1	0	1	2	2	6	4	16	8.38
Quality Systems knowledge	0	1	0	0	1	0	2	3	7	2	16	8
Project Management	0	1	2	0	0	0	2	5	2	4	16	7.5
Environment, occupational health and Safety	0	1	0	0	5	1	1	1	4	3	16	7.13
Business knowledge and skills	0	0	0	0	3	5	3	0	3	2	16	7.06
knowledge and competency in production m	0	0	0	1	2	3	2	5	3	0	16	7.06
Specific Manufacturing process knowledge	0	0	2	0	1	3	2	4	3	1	16	7
Supply chain management	0	1	0	1	4	3	1	0	3	3	16	6.75
Technical drawing	1	0	2	1	2	0	5	0	4	1	16	6.38
Knowledge raw materials	0	0	3	1	5	2	2	2	1	0	16	5.56

3.5.2 Establishing potential manufacturing laboratory elements and level of instruction required for effective learning

With a large of number of potential elements that could be integrated as part of hands-on manufacturing education, it becomes necessary to classify all the elements according to how important each of these elements are to the manufacturing industry and thus prioritize them for inclusion in a manufacturing curriculum. A comprehensive list of these elements was given in section 3.3. Erevelles (1996) had hypothesized that the academic community would classify some of these elements as more important in an instructional laboratory than other elements. He went on to conduct a survey to capture those perceptions. We will discuss some of these findings along with our own survey results that sought the perceptions of manufacturing industry professionals. In ranking the potential elements, four levels of importance (Necessary, Useful, Optional, and Not needed) were used as shown in figure 3.4

. In addition to classifying each element according to importance , it was also necessary to understand what method of instruction could be used to teach that particular element to effectively elicit student learning. These levels of instructions range from one being able to teach effectively at the conceptual/theoretical to one in which industrial grade equipment would be required to teach effectively. These teaching levels are illustrated in figure 3.3

Q13:Statement 13-Establishing potential product design elements for hands-on integration.

Participants were asked to rank a list of elements associated with product design using the importance scale discussed (necessary, useful, optional and not needed). In addition to ranking the importance of each element, they were required to offer their perceptions regarding the minimum teaching level required to effectively teach that element. Figure 3.5 and figure 3.6 shows the results of academia perspectives (Erevels, 1996) and industry perspectives from this study respectively.

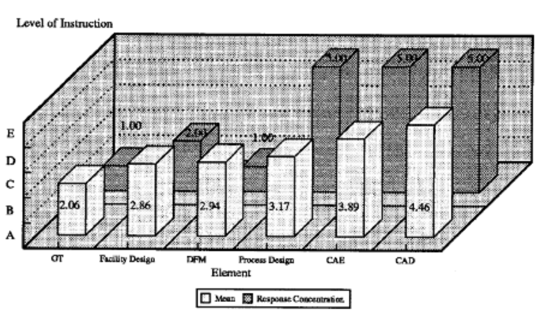


Figure 3.5: Academia perspective of product design elements, Ereveles (1996)

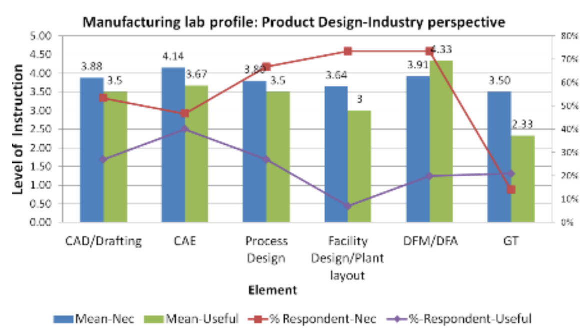


Figure 3.6: Manufacturing industry perspective of product design elements

Figure 3.6 shows that most academia survey respondents indicated CAD,CAE, and Process design as the important elements of product design. They also indicated that for effective learning to occur, each of those elements would be needed to teach above the physical level of instruction, with CAD requiring industrial grade/commercial software to be effectively taught. On the other hand, survey respondents from the manufacturing industry favored

Process design, facility design, and DFM/DFA as integration elements. They believed those elements needed to be taught at a minimum using scaled down equipment as indicated in figure 3.6.

Q15:Statement 15-Establishing potential automation and new technologies elements for hands-on lab integration.

In a similar manner to Q13, participants were asked to rank various elements of automation and associated technologies according to importance. In addition to the ranking, the respondents were also required to suggest the method of instruction that was adequate to elicit students' effective learning of that particular element. Responses to these survey questions are summarized in figure 3.7 and figure 3.8. In a survey conducted by Erevelles, 2006 in which the perception of academia was sought, findings suggested that automated assembly, automated manufacturing handling, robotic assembly, Computer numerical control, and sensors are important elements that needed to be taught using a minimum of scaled down equipment or industrial grade equipment.

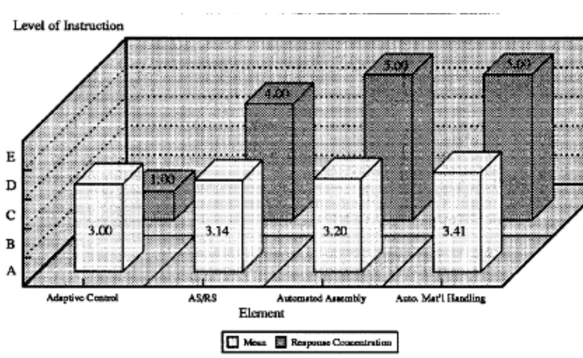


Figure 3.7: Academia perceptions of automation and new technology elements integration, Ereveles (1996)

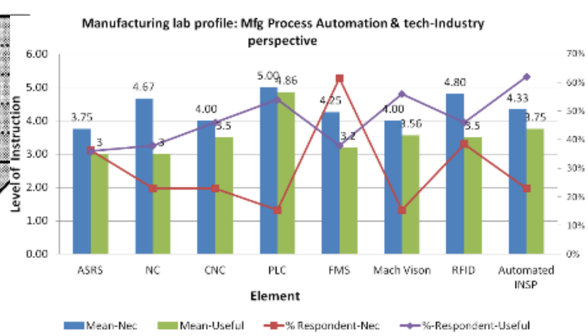


Figure 3.8: Manufacturing industry perceptions of automation and new technology elements integration

Figure 3.8 shows the summarized responses from manufacturing industry respondents. Industry respondents believed that the elements indicated in figure 3.8 are necessary to include in a manufacturing curriculum. A majority of respondents perceived flexible manufacturing systems (FMS), programmable logic controller (PLC), and Automated storage and retrieval systems (ASRS) as important elements in any manufacturing curriculum. Respondents found it necessary that FMS and RFID be taught using industrial grade equipment/Software, while teaching at the scaled down version was perceived as adequate for teaching ASRS. In addition, a relatively larger percentage of respondents indicated that automated inspection, PLCs, and machine vision would be useful elements to include in an effective manufacturing curriculum.

Q17:Statement 17-Establishing potential Manufacturing planing elements for hands-on lab integration.

In a similar manner, participants in both academia and manufacturing industry were asked for their perceptions of what elements of manufacturing planning would be important for integration in a manufacturing curriculum, and what method of instruction would be adequate for effectively teaching the identified elements. The results are shown in figures 3.9 and 3.10. According to academia perspectives the most important element associated with manufacturing planning are NC part programming, Computer aided process planning, and MRP. On the other hand, manufacturing industry survey respondents indicated that time studies, assembly line balancing , and capacity resource planing (CRP) are necessary elements in a manufacturing curriculum. Each of these elements were identified as requiring instruction at the physical level or above as indicated in figure 3.10

3.5.3 Discussion

All elements that are deemed as necessary can be considered as the must have elements in a manufacturing curricula, while the useful elements are those that are considered good to have. It is thus prudent to say that necessary elements could be those elements that

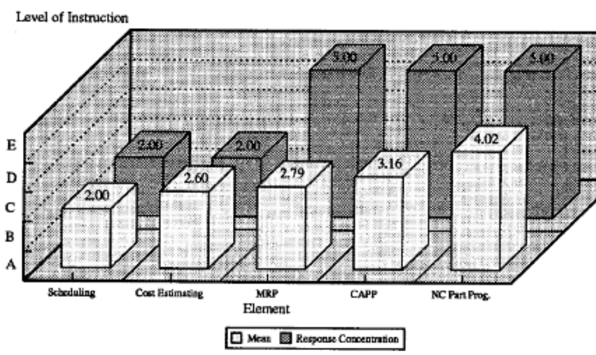


Figure 3.9: Academia perceptions of manufacturing elements integration, Ereveles (1996)

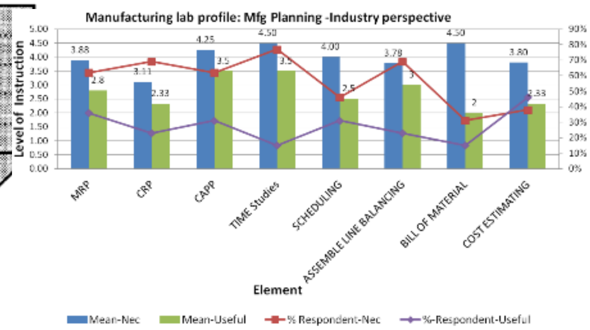


Figure 3.10: Manufacturing industry perceptions of manufacturing elements integration

should be considered for inclusion as part of requisite courses while useful elements could be considered for inclusion in elective courses in a manufacturing curricula. The perceptions of respondents from manufacturing industry displayed some similarities with those academia as reported by (Erevelles, 2006). However differences in perceptions on the importance of each identified element and associated teaching level prescribed still existed. There is therefore the need to balance the perceptions of both industry and academia in building and effective manufacturing taxonomy. Table 3.10 shows a summary that could be used as guideline for setting up a new hands-on oriented manufacturing curriculum.

Table 3.10: Industry and academia perceptions of the important manufacturing elements and associated teaching levels

	Minimum teaching levels for necessary elements			
Product Design	**Industry**	**Importance Scale**	**Academia**	**Importance Scale**
DFM/DFA	Industral Grade	Necessary	Scaled hardware and software	Necessary
Facility Design	Scaled software	Necessary	Simulation/CAD/Software	Necessary
Process Design	Scaled hardware & Software	Necessary	Scaled hardware and software	Necessary
CAD	Scaled hardware and Software	Necessary	Scaled and industrial Grade and Software	Necessary
Manufactuirng Planning				
Time Studies	Industrial Grade hardware/Software	Necessary	**N/A**	
Assembly line balancing	Scaled Software	Necessary	**N/A**	
Capacity resource planning	Industrial Grade hardware/Software	Necessary	Commercial software	Necessary
Material resource planning	Scaled down software	Necessary	Commerccial shop floor control software	Necessary
Scheduling	Commercail software	Useful	Commerccial software	Necessary
Cost estimating	Scaled software	Useful	physical modelling/Computer simulation	Necessary
Bill of Material	Commercial software	Optional	Industrial Grade hardware/Software	Optional
Manufacturing Automation and Tech				
FMS	Scaled hardware and Software	Necessary	Scaled down equipment	Necessary
RFID	Industrial grade equipment/software	Useful	**N/A**	
CNC	Industrial grade hardware/Software	Useful	Industral Grade hardware/so	Necessary
Automated inspection	Industrial Grade hardware/Software	Useful	**N/A**	
Programmable logic controllers (PLCs)	Industrial Grade hardware/Software	Useful	Industrial Grade hardware/Software	Necessary
Machine Vison	Industrial grade	Useful	Scaled Equipment	Necessary

Chapter 4

Developing the lab for bridging competency gaps of manufacturing graduates

The first step in developing a best practice manufacturing education and research laboratory, where integrated topics in manufacturing span various functional areas, is the creation of the model physical factory. This factory should have various appropriate hardware components as well the product to be manufactured. In the case of the Auburn Manufacturing lab, a small scale Lego based model automobile assembly plant (Tiger Automotive) that is used to assemble 3 models of a Lego vehicles was selected. The creation of educational systems that emulate the complexity of industrial systems for studying manufacturing systems is not a trivial task. In order to create an environment with the intricacies of an industrial setting, three models of Lego cars were selected, namely: the Speeder, SUV and a Convertible model (See, Figure 8). These models have a total of 96 unique parts that are used for assembly and as many as 270 parts going into the assembly of a vehicle. The idea of using Lego for educational purposes is not a new idea. Several examples exist of the use of the Lego concept in tertiary education and research for manufacturing systems simulation, Lean manufacturing principle, mechanism design, and virtual prototyping. However, a study of the documented activities did not yield an example that compares in size and scope as the one being developed at Auburn University's Industrial and system department.

4.1 Tiger Motors floor layout and workstation design

A mixed model assembly line with 15 stations was selected to be used for assembling two models of vehicles on a mixed assembly line. The manufacturing system was designed

Speeder-SP	Speeder-Model-SUV	Convertible-Conv

Figure 4.1: Models of Vehicles assembled at Tiger Motors

to incorporate some element of (CIM). This was achieved by designing a semi automated workstation complete with machine vision capability for automated inspection. All the manual workstations were retrofitted to allow re-reconfigurability of the manufacturing system. The re-reconfigurability of the layout allows students to experiment with different layouts discussed during the lecture. The proposed shop floor layout is shown in figure 4.2. Students worked in teams in solving line balancing problems (LBP). Each team was allocated a manufacturing work cell (Cell-1, Cell-2 and Cell-3, as depicted in figure 4.2) whose workstations were characterized by unbalanced workloads . Each team was led by a team leader who was responsible for coordinating the activities of the cell. Unlike textbook line balancing problems, the lab line balancing problem was more realistic, similar to a real world line balancing problems. The lab line balancing problem had the following additional tasks:

1. Students establish standard times using stop watch time study or any the predetermined time motion studies (PTMS)

2. Students establish precedence constraints from assembly charts

3. Students establish resource and zoning constraints

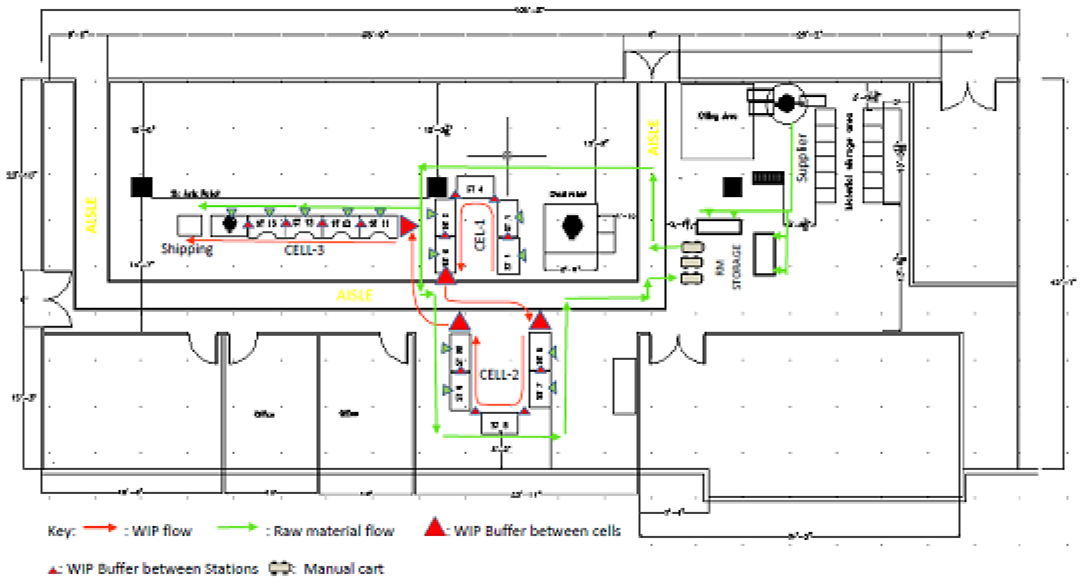


Figure 4.2: Material replenishment routes

The red arrows depict the flow of raw material stock from the storage area to the point of use at each workstation, while the green arrows depict the flow of work in process material (WIP) along workstation and manufacturing cells. It is evident from 4.2 that the manufacturing system is arranged in three distinct departments , namely:

1. Under-body/Chassis Assembly

2. Cab Assembly

3. Trim/Final Line

Cell 1 is where production begins. Cell 2 and Cell 3 are progressively upstream departments. Cell 1 products all go to the beginning of Cell 2, and similarly all Cell-2 output goes to beginning of Cell 3. Students are divided into equal groups and assigned to a manufacturing cell. Each manufacturing Cell acts as an autonomous department responsible for decisions associated with running that particular cell.

Cell-1/Cell2: U shaped Configuration	Cell 3: Straight line Configuration

Figure 4.3: Tiger motors Lay out configuration used

The semi-automated assembly station consists of Selective Compliance Assembly Robotic Arm (SCARA) Adept One Robot. This Adept One Robot is a three axis robot which is suitable for assembly operations. This station serves the purposes of teaching students aspect of automation in assembly operations, in particular robotic programing as well as for demonstration purposes. The robotic assembly station has the ability of be integrated into the system, replacing a manual workstation in Cell-1. Because of the large class size and safety concerns, student interaction with the robot was only limited to demonstration purposes. However, through the use Adept Ace Emulation software, students were taught hands-on robotic programming.

4.2 Design and implementation of material replenishment strategy for Tiger Motors Manufacturing system

One of the challenges that was faced in designing Tiger Motors Manufacturing system was planning for material replenishment and implementing an efficient shop floor material delivery system. Traditionally MRP has been the system of choice as a means of ensuring that material needed for production is available to meet demand. MRP planning was pioneered in the 1970s by Joseph Orlicky and others and later got a boost when the American

Production and Inventory Control Society (APICS) launched its MRP crusade to promote its use. Since that time MRP has become a principal production control paradigm (Hopp & Spearman, 2001., p. 110). MRP is a push system since it works backwards from a production schedule of an independent demand item to derive schedules for demand components. MRP computes schedules of what should be started or pushed into production based on demand. However, there are inherent disadvantages associated with using MRP, which include the cost associated with software, which often needs maintenance from a well qualified personnel . An alternative to MRP is a much newer Kanban production control which is a simpler, more visual system, and more responsive system. It is therefore important for students in manufacturing to have an innate understanding on how both systems work so as to be in a position to apply the tools appropriately. In this section we discuss the development of Kanban controlled production material replenishment systems. A review of literature on how to teach MRP in a laboratory setting revealed a scarcity of information. MRP software is expensive and is difficult for educational institutions to acquire for the purpose of acquainting students with its intricacies. However, to demonstrate the difference between the workings of the two systems, two master production schedules, each representing the normally large batch sizes associated with MRP systems, and the smaller batch sizes associated with leveled production found in pull based manufacturing systems were demonstrated as illustrated in 4.3

MRP Master Schedule										
SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP
SP	SP	SP	SP	SP	SP	SP	SP	SP	SUV	SUV
SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV

Kanban Master Production Schedule									
SP	SP	SP	SUV	SUV	SP	SP	SP	SUV	SUV
SP	SP	SP	SUV	SUV	SP	SP	SP	SUV	SUV
SP	SP	SP	SUV	SUV	SP	SP	SP	SUV	SUV

Figure 4.4: Master Production Schedule: MRP Vs Kanban

The master schedule is specific regarding the products to be manufactured through the planning horizon. Although the planning horizon for MRP and Kanban could be similar, typical differences lie in how the products are sequenced and lot size as depicted in figure 4.4. For a variety of reasons that we will not dwell on , the lot sizes in MRP systems are much bigger than in Kanban systems. In conducting the lab, the effect of lot sizes on the performance of the manufacturing system was demonstrated. In the the implementation of a Kanban system, key decisions that needed to made included the choice of a material replenishment system. In assembly systems, three distinct material replenishment strategies are typically available, namely:

1. Line-stocking
2. Kitting
3. Kanban Continuous supply

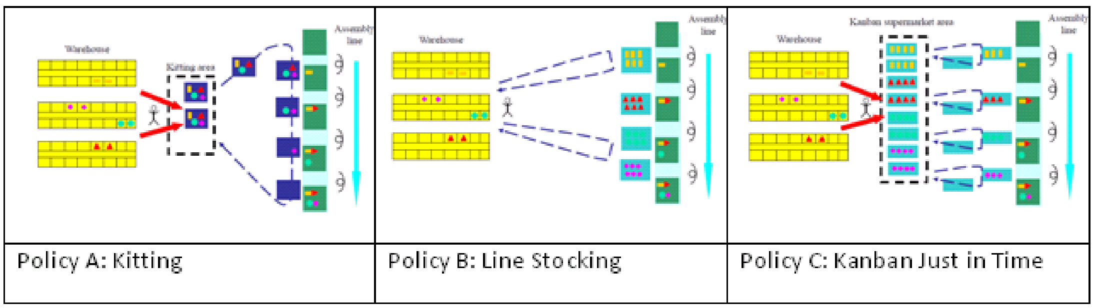


Figure 4.5: Material replenishmentpolicies

In order to make a choice among the strategies listed, there was a need to understand how each of them work and how they would impact the overall efficiency of the manufacturing system with regards to Work in Process (WIP), material handling effort, space utilization, and personnel requirement and costs. Although acknowledging the availability of a number of quantitative methods for deciding on replenishment policy, the selection of policy in this particular case was solely based on qualitative comparisons, as the main aim was to increase awareness of the different strategies.

4.2.1 Kitting material replenishment strategy

In kitting, parts inventories are kept at the assembly stations, with an assortment of parts required for a specific operation all put into one container. The kits are prepared in a central stockroom utilizing a pick list generated from an order of bill of material. This method was not selected for use at Tiger Motors based on the fact that it is labor intensive and requires generation of a pick list which is tedious to accomplish, taking into account the numerous re-balancing of the line which is typical of assembly lines.

4.2.2 Kanban based just in time replenishment strategy

In this strategy each different part number is put in an individual container and supplied to the assembly line (figure 4.5). Component containers are moved just in time to the point of use leading to a continuous flow of material. This strategy requires the set up of a supermarket where exchange of empty containers and full containers is done. A key decision regarding this strategy concerns establishing the quantities of parts in each container, and ultimately the frequencies of deliveries to be made to point of use. This leads to a trade-off between service level , holding cost, and transportation cost. This strategy was selected because it is the easiest to implement since it is manual based, solely relying on kanban cards as the control mechanism.

4.2.3 Line stocking

This is the traditional system and parts are stored in bulk containers along the line and periodically replenished. This strategy requires bigger containers, and raw parts and is expected to last much longer before replenishment is done. The frequency of volume moves is less, however the holding costs are higher with line stocking.

Description of components parts used for assembly

On average each vehicle at Tiger Motors uses around 273 parts and there are about 95 unique parts. Lego is a popular line of construction toys manufactured by The Lego Group. It consists of colorful interlocking plastic bricks. Lego bricks can be assembled and connected in many ways, to construct objects such as toy vehicles and buildings among many others. Lego pieces come in 3 main different classes as indicated below:

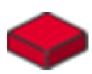
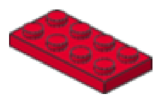
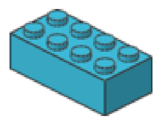
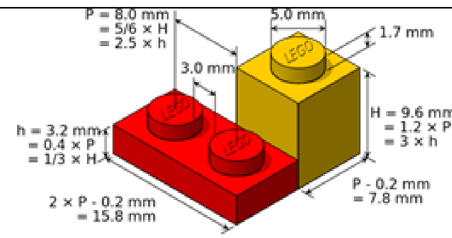
	Lego brick types			
	Tile	plate	Brick	Lego dimensions
				
Volume	1	8	24	

Figure 4.6: Categories of Lego Bricks

Considering the large number of parts used in each vehicle, the raw material replenishment was a challenge. The goal was to demonstrate material replenishment strategy using the Kanban replenishment strategy. Establishing the stock levels for each part type thus became important. The stock level established for each part contained in replenishment bins establishes the frequency at which each part in the bill of material was to be replenished.

To prioritize the replenishment intervals for different parts, ABC classification inventory classification was used. In ABC inventory classification, three categories of inventory are recognized. The A class inventory which is considered to represent the critical few items that constitute biggest cost, the B class which is the immediate class, and the C class consists of the trivial many. the boundary between the classes is usually a matter of company policy.

In this project establishing the cost of individual parts was a challenge since vendors do not sell individual parts, but sell kitted units. To overcome this obstacle it has been assumed that the cost of each part is proportional to its volume. The volume of each part in the assembly bill of material was established. Therefore multiplying the volume of each part in the BOM with the frequency that the part is used in each vehicle establishes the total volume requirements of that part in a vehicle. Figure 4.7 shows a partial table used to calculate the required Kanban quantities. If the number of containers used is not an issue then the number of containers required at station j to avoid starving was calculated in Column p. However, Tiger Motors had a limited number of containers, thus the decision to adopt a 2 bin system. The corresponding container quantities for this system is shown in column k.

VC_1	2000	Hourly Demand		50
VC_2	231			
VC_3	125			
LT_1	20			
LT_2	25			

	Station (j)	Part Number (i)	Serial Number	Operation Number	Number of Parts required (nij)	L	W	H	Vol/unit	Tot Vol	Cumu Vol	%	VC_i	Cont size	N_{ij}	parts/ container	2 bin syst
1	15	80	4550937	48	4	3.1	4	5	62.86	251.44	251.44	0.16	2000	7.95	2.1	32	33.333
2	15	87	4299119	48	4	3.1	1	5	15.7	62.8	314.24	0.20	231	3.68	4.5	16	33.333
3	1	41	4506961	3	1	10	6	1	60	60	374.24	0.23	231	3.85	4.3	4	8.3333
4	1	73	244526	1	2	12	2	1	24	48	251.44	0.16	231	4.81	3.5	10	16.667
5	1	71	303226	4	2	6	4	1	24	48	299.44	0.19	231	4.81	3.5	10	16.667
6	2	50	4205058	10	2	4	2	3	24	48	347.44	0.22	231	4.81	3.5	10	16.667
7	7	28	366021	25	4	2	2	3	12	48	395.44	0.25	231	4.81	3.5	20	33.333
8	14	48	4542700	46	1	2.5	3	6	45	45	440.44	0.27	125	2.78	6	3	8.3333
9	8	47	4129534	29-SA-3	1	4	1	9	36	36	476.44	0.30	231	6.42	2.6	6	8.3333
10	11	28	366021	36	4	1.5	3	2	9	36	512.44	0.32	231	6.42	2.6	24	33.333
11	5	72	303426	19	2	8	2	1	16	32	544.44	0.34	231	7.22	2.3	14	16.667
12	7	39	303421	26	2	8	2	1	16	32	576.44	0.36	231	7.22	2.3	14	16.667

Figure 4.7: Excel formulation of Kanban quantities

Using column k (total Volume), a Pareto chart was drawn to establish the priority by which parts needed to be controlled.

Figure 4.7 illustrates the classification of raw materials in the bill of materials. The classification is as follows:

Class A: Raw material that cost the most and accounts for above 50 % of the total cost of raw material used in the vehicle. This classification of raw stock will be replenished

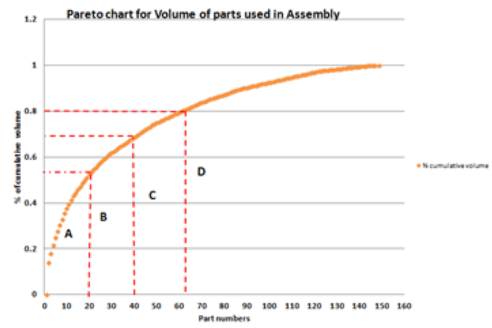


Figure 4.8: A-B-C-D classification of raw material stock

three times during a production run. Around 13% of the raw stock accounts for 50% of the total cost of raw material.

Class B In this category are those parts which are only replenished twice during the production run (Shift). These parts make next up 13% of total number of parts in the BOM. These parts account for about 16% of the total cost of the car.

Class C In this category you find parts that are only replenished once during a shift. These parts consist of about 13% of the total number of parts in the BOM and account for about 12% of the total cost of a vehicle.

Class D In this category you find parts that do not need to be replenished during a shift. These parts consist of around 60% of the total number of parts in the BOM but account for only 20% of the total cost of the car.

4.2.4 Establishing the adequate number of Kanban card for each part

Material required in the cells were retrieved from the ASRS (location 1) as illustrated in figure 4.2 and temporarily stored in SuperMarket buffer. At the SuperMarket, material handlers pick parts as indicated on a Kanban card attached to the empty bin and place them in the bin. The Kanban card contains information about the quantity of raw material that is required at a particular station within a cell. The Kanban cards will be used as the basis for which raw material replenishment is done. The individual part numbers will be stored in the ASRS system. Material from the ASRS system will thus be retrieved as needed in the cells. Using a Kanban material replenishment policy, material is resupplied at each station with a lead time of LT in separate containers dedicated to each component type. Defining n_{ij} as the number of items of the component utilized at station j. Then, the number of containers needed at station j to hold the material needed to avoid starving during the supply lead time (with zero buffer stock) is n_{contij} and the total number of utilized containers is N_{ctot}.

$$n_{contij} = \frac{LT \times D \times n_{ij}}{min[\frac{V_c}{v_i}, \frac{p_{max}}{p_i}]} \tag{4.1}$$

$$N_{ctot} = \sum_{j=1}^{M} \sum_{i=1}^{N} n_{contij} \tag{4.2}$$

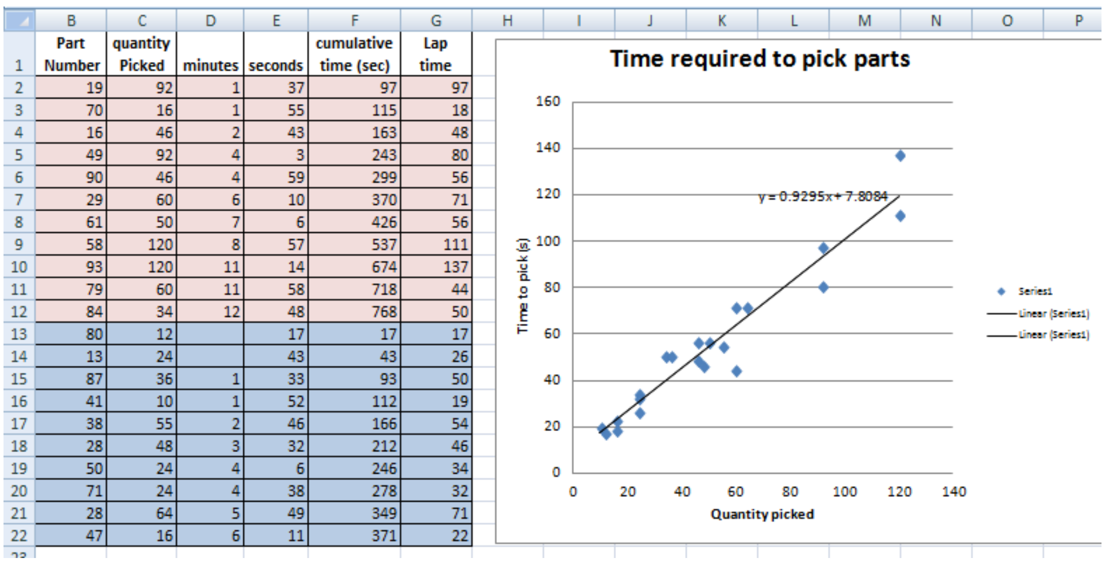
$\frac{Vc}{vi}$ in equation 4.1 above represents the standard number of units of part i that can be held in a standard container size. The supply lead time $LTDn_{ij}$ can be viewed as an estimate of how long the consuming process will need to wait for parts once replenishment has been authorized. The replenishment lead time dictates the number of parts that must be available at the consumption point to assure production can continue uninterrupted until replenishment parts arrive. The larger the replenishment lead time ($LTDn_{ij}$) , the greater the amount of inventory in the system. Factors that may influence $LTDn_{ij}$ include (Vatalaro

& Taylor, 2003, p. 42): (1) The number of orders that arrived at the supplying process ahead of the one just sent, (2) Service time at the point of use, (3) Quantity of parts in the container, (4) The replenishment signal method, and (5) Product transit time.

For the purposes of this project, 3 different sized containers were selected for holding individual parts. The bigger containers are used for the larger volume parts while the small containers are used for small volume parts. Taking into consideration the 1 hour available time to conduct live simulation runs, two sets of replenishment lead times were selected to be used. In accordance to ABCD inventory classification, Class A parts were assigned a lead time $LTDn_{ij}A$ of 10 minutes, while Class B parts were assigned $LTDn_{ij}B$ of 15 minutes. Class C and D parts are replenished once and expected to last the entire simulation run. Since the parts used in our systems were small in volume compared to the size of the container, a 2 bin material replenishment was implemented (see Column R in figure 4.7 on page 68. In the 2 bin system, $n_{contij} = 2$. To establish container quantities for each part type i at station j , equation 4.3 is utilized. Qty_{contij} is the quantity of parts needed in each container in a 2 bin system, D is the Demand (Units/ hour), and n_{ij} is part count of part$i$ that is needed at station j.

$$Qty_{contij} = \frac{LT \times D \times n_{ij}}{2} \tag{4.3}$$

The objective for the parts replenishment for the AU Model Manufacturing Factory is to maintain minimum inventory while ensuring that parts required during the production period (physical simulation run) do not run out. A minimum of 24 students, divided into 3 groups of 8 students each, are required to do simulation run lasting 1 hour. Each team is assigned to a manufacturing cell (see figure 4.3), and is empowered with making decisions that affect the performance of their respective cells. The frequency of replenishment cycles and thus the amount of inventory in the system is constrained by the capabilities of the personnel that each team assigns to this task. The material replenishment team is responsible for restocking the parts bins with the right quantities of material and ultimately delivering them to the work cells at the right time. It is important to note that in the formulation of the 2 bin material replenishment strategy of Tiger Motors the replenishment lead time is established. The key has thus become establishing the resources needed to meet this objective. LT is a function of the capacity of material handling people to refill the empty containers at the supermarket. A stopwatch time study was carried out to establish the amount of time required to pick parts at the supermarket, the results of which are illustrated in figure TimetoPickparts .



	B	C	D	E	F	G
1	Part Number	quantity Picked	minutes	seconds	cumulative time (sec)	Lap time
2	19	92	1	37	97	97
3	70	16	1	55	115	18
4	16	46	2	43	163	48
5	49	92	4	3	243	80
6	90	46	4	59	299	56
7	29	60	6	10	370	71
8	61	50	7	6	426	56
9	58	120	8	57	537	111
10	93	120	11	14	674	137
11	79	60	11	58	718	44
12	84	34	12	48	768	50
13	80	12		17	17	17
14	13	24		43	43	26
15	87	36	1	33	93	50
16	41	10	1	52	112	19
17	38	55	2	46	166	54
18	28	48	3	32	212	46
19	50	24	4	6	246	34
20	71	24	4	38	278	32
21	28	64	5	49	349	71
22	47	16	6	11	371	22

Figure 4.9: Time required for picking parts at SuperMarket

After a regression relationship shown in figure 4.9 that enabled the amount of time required to pick parts was established, it became possible to determine the amount of time that would be required to pick all the parts of a particular class, thus enabling the determination of manpower requirements for fulfilling parts replenishment with starving the station in each cell.

Figure 4.10 shows an excel formulation that was used for determining the replenishment time requirements as well as input for automated printing of Kanban cards. The time required by one man to replenish all parts of a certain class is shown in cell range (Z5:AB7). For instance, all group A parts are always replenished after 8 cycles while group B parts are replenished after 13 cycles. For example a total of 14 minutes is required to replenish all

Super Market Address		Station (j	Part Number (i)	Serial Number	Operation Number	Number of Parts require	container Quantity	Time (A)	Cumu time (A)	Time(B)	Cumu time (B)
A	1	1	2	300401	6	1	13	0.00	0	19.8854	19.8854
A	2	1	38	447721	5	1	13	0.00	0.00	19.8854	39.77
A	3	1	40	383221	3	1	8	15.24	15.24	0	39.77
A	4	1	41	4506961	3	1	8	15.24	30.48	0	39.77
A	5	1	54	4124067	2	2	13	0.00	30.48	31.9624	71.73
A	6	1	65	243126	11	2	13	0.00	30.48	31.9624	103.70
A	7	1	71	303226	4	2	8	22.67	53.15	0	103.70
A	8	1	73	244526	3	3	8	30.10	83.26	0	103.70
A	9	2	82	4211529	8	2	8	22.67	105.93	0	103.70
A	10	2	13	300421	10,12	2	8	22.67	128.60	0	103.70
A	11	2	14	245821	14	2	8	22.67	151.27	0	103.70
A	12	2	15	362221	14	2	8	22.67	173.95	0	103.70
A	13	2	16	4157223	7	2	10	0.00	173.95	0	103.70
A	13	2	16	4157223	13	2	10	0.00	173.95	0	103.70
A	14	2	50	4205058	10	2	8	22.67	196.62	0	103.70
A	15	2	56	362226	10	2	8	22.67	219.29	0	103.70
A	16	2	83	4211385	9	1	8	15.24	234.53	0	103.70
A	17	2	90	4211060	13	1	13	0.00	234.53	19.8854	123.58
A	18	3	10	306201	SA-1-1	2	13	0.00	234.53	31.9624	155.54
A	19	3	20	4251162	SA-1-3	2	13	0.00	234.53	31.9624	187.51
A	20	3	21	243221	SA-1-4	2	8	22.67	257.20	0	187.51
A	21	3	27	4121934	SA-1-1	2	13	0.00	257.20	31.9624	219.47
A	3	3	40	383221	SA-1-1	1	8	15.24	272.45	0	219.47
A	22	3	68	371026	SA-1-2	1	13	0.00	272.45	19.8854	239.35
A	10	4	13	300421	12	2	8	22.67	295.12	0	239.35
A	23	4	17	621521	12	1	8	15.24	287.69	0	239.35
A	24	4	69	346026	18-SA-1-5	1	13	0.00	287.69	19.8854	259.24
A	25	4	72	303426	19	2	8	22.67	310.36	0	259.24
A	5	5	54	4124067	16	2	13	0.00	310.36	31.9624	291.20
A	26	5	63	4227684	17	2	13	0.00	310.36	31.9624	323.16
A	27	5	70	4243819	16	1	8	15.24	325.60	0	323.16
A	28	5	74	302226	20	4	8	37.54	363.13	0	323.16
A	29	5	81	486526	21	3	13	0.00	**363.13**	44.0394	**367.20**

	Tim required to pick parts/man (mins)		
	Class A	Class B	Total time required
Cell 1	7	7	14
Cell 2	5	7	12
Cell 3	4	3	7

Figure 4.10: Establishing time required for picking parts at Supermarket

parts in Cell-1. Referring to the figure 4.10, column D contains the part number, column F contains the operation number, and columns A and B contain the supermarket address where the part is stored in the supermarket. Column C contains the station where the part is used. Column C is determined by line balancing which assigns operation to stations. Once all of the Kanban quantities and assignment of operations to stations were done, printing of Kanban cards was the next required step. Because table 4.10 contains all the information needed in a Kanban card, a worksheet for printing kanban cards that referenced particular cells containing pertinent information in table 4.10 was created.

4.2.5 Automatic Kanban card updating and printing formulation in Excel

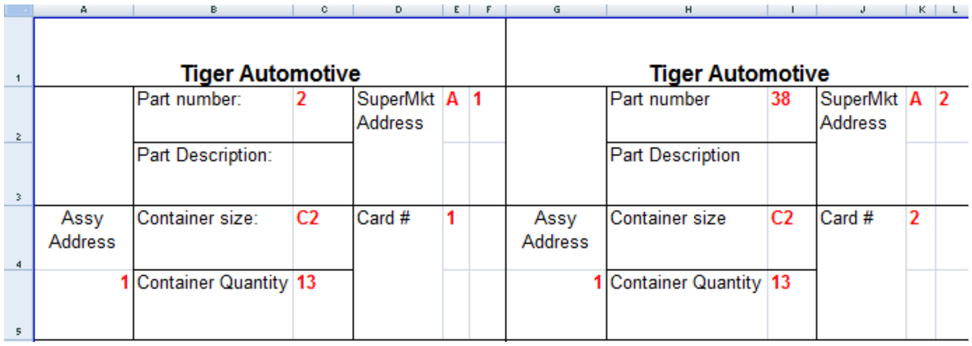


Figure 4.11: Kanban card automatic updating excel worksheet

Figure 4.11 shows the kanban card used for authorized replenishment of material to the stations. The kanban displayed shows key information necessary for the running of a kanban pull system. The following minimum information is displayed on the kanban card:

- Part identifier identifies the part type required. Figure 4.11 shows two kanban cards used for part numbers 2 and 38.

- The external and internal supply process. The supermarket address A1 and A2 indicates where the part numbers 2 and 38 are to be located in the upstream supplying process.

- The container quantity is important as it determines the permissible stock quantities needed in each container to avoid starving at the downstream consuming process. These quantities were calculated using equation 4.3 in the excel worksheet 4.10.

- The Assay address indicated in Cell A5 shows the consuming process. This shows where the container of parts is to be delivered to. The displayed Kanban card indicates station 1 as the consuming process. Because this assembly address can change depending on the line balancing solution or re-balancing of the line, it was necessary to create an automated Kanban updating. All the information described above is linked to Excel, a database that automatically updates the Kanban information subjected to revisions.

Figure 4.12: Container arrangement at a workstation

Figure 4.13: Kanban card attached to a container

Figure 4.14: SuperMarket intermediate storage area

Figure 4.15: Push cart for material delivery

Figure 4.12 through figure 4.15 illustrated the implemented material replenishment system at Tiger motors. As per ABCD material classification described, class A and B materials were replenished on a regular interval as indicated by 2 bin Kanban system (see figure 4.12). Figure 4.13 shows the Kanban card attached to parts container. The raw material needed at each station is stored at the supermartet shown in figure 4.14. A material handler used the cart shown in figure 4.15 to replenish parts at regular intervals.

4.3 design of a hands-on assembly line balancing lab

Assembly line balancing is an integral part of manufacturing systems where assembly operations are common. The textbook assembly line balancing problem is an oversimplified version of the real world assembly line balancing problem and does not provide the student with a realistic assembly line balancing experience. It is on this basis a realistic assembly line problem that has been implemented. The simplest form of the assembly line balancing problem is dubbed SALBP (Simple Assembly Line Balancing Problem), and was used as basis for developing the hands-on learning lab.

4.3.1 Introduction

The Classic assembly line balancing problem is a problem where a given set of tasks, task durations, precedence constraints among the set of tasks, and a set of workstations, assign each task to exactly one one station in such a way that no precedence constraints are violated (Becker and Scholl, 2004). When a fixed cycle time is given, the cumulative task time for any particular station cannot exceed the cycle time. this type of line is called paced line. In paced lines the cycle time cannot be smaller than the largest task time. A good example of a paced line is an assembly with stations linked by a conveyor belt. On the other hand, in the absence of fixed cycle time, all stations operate at individual speeds and instances of a workstation becoming idle are of common. To mitigate the effects of station idleness buffers can be used between stations. Unpaced lines are thus faced with the additional decisions of sizing the buffers, as well as positioning the buffers within the line. Since assembly line balancing is a very common and important problem in many manufacturing environments, it was selected as a practical problem that would allow students a realistic environment for implementing assembly line balancing. LB is a classic operations research optimization problem that has been studied for many years. Despite the efforts that academics have expended on this problem, there are still are a few commercially available types of software to help industry deal with this problem (Becker & Scholl, 2006).

Assembly line can take many variants. If one product is assembled, then the assembly line is a single model assembly line. This is the simplest variant of the assembly line since all work pieces are the same. If several products are assembled on the same assembly line, a mixed model assembly line results, and there is the additional sequencing problem that is needed to determine the sequence in which models are introduced into the line. If the same line is used produce different models, with each model introduced to the line as a batch and with the different models separated with intermediate setup operations, then multi-model line results with inherent need to determine the lot sizes of vehicles that are introduced to the line. Another important characteristic of assembly lines that is often ignored is the considerable variation due to the instability of humans with respect to work rate, skill and motivation. This leads to highly stochastic assembly task times. However, the stochastic nature of tasks can be reduced through learning effects or successive improvement of production processes ((Boucher, 1987; Chakravarty, 1988). In general, the variance of task times increases with complexity. Various distributions for task times have been suggested by different researchers. Moodie and Young (1965) for example assumed tasks times to be independent normal variates which can be considered realistic for human work.

4.3.2 Mixed models assembly Lines:

Mixed- model lines manufacture several models of a standardized commodity in an intermixed sequence. The models may differ with respect to size, color, material used, or equipment used on them. As a result the task times of the models differ and the challenge is to determine a line balance whose station loads have the same station time and equipment requirements for whatever model is produced. This requires flexibility in the equipment used and the qualification of operators. Finding a line balance where the stations loads have the almost identical station time and equipment requirement offers the greatest challenge in mixed-model assembly. In addition to balancing workloads between stations in mixed model assembly, the sequencing of models is an important aspect of mixed model assembly. If several work intensive models follow each other at the same station, the cycle time might be exceeded, which requires some kind of reaction to overcome it (line stoppage, utility workers, offline workers)(Boysen, Fliedner, & Scholl, 2008). The only way of avoiding exceeding the cycle time is to find the sequence for the models which cause high station times to alternate with less work intensive ones at each station.

4.3.3 multi-model assembly lines

Multi-model lines produce different variants of product and are produced in batches because the uniformity in products is not sufficient to enable ease and quickness of changeovers from one product to the other. In this instance a trade off problem occurs when deciding batch sizes and sequences.

4.3.4 Formulation of assembly line balancing problem

SALBP usually takes into account two constraints which may be cycle time and precedence constraints, or the precedence constraints plus the number of workstations.

4.3.5 Inadequacies of SALBP

The constraints used in SALBP can in many cases be insufficient for adequately addressing practical assembly line balancing problems that normally are more complex and exhibit far greater numbers of constraints than considered in SALBP. Despite this inadequacy SALBP has remained the single most researched variant of assembly line balancing problem by academics. This inadequacy of the SALBP has not escaped the attention of researchers, thus the development of the generalized assembly line balancing problem (GALBP) which is an extension of SALBP. Although even simple SALBP is NP hard, in most cases it fails to capture the true complexity of the problem in real life. GALBP is thus an attempt to close the gap between the academic LB problem and actual problem being faced by industry. Despite the difficulty of solving assembly line balancing problems to Optimality, many assembly line balancing problems and small instances of the problem can even be solved close to optimality by hand, thus making the case for the development of commercial assembly line balancing software a difficult one to make. It is therefore not surprising to see that there is a depth of commercially availably assembly balancing software in the market today.

(Falkenauer, 2005) outlines some inadequacy of the SALBP as it relates to the real life problem found in industry. The SALBP problem assumes that the assembly line balancing problem is that of a new, yet to be developed facility, yet this is hardly the case as a majority of real world line balancing problems involve existing lines needing to be rebalanced. SALBP also fails to consider operation and zoning constraints that are a common occurrence in many assembly lines. An operation is considered unmovable if it must be assigned to a given workstation. This is due to some kind of heavy equipment that is unmovable or too expensive to move. Another assumption of SALBP which may be problematic is the assumption that workstations can be eliminated. In most real world cases, elimination of workstations can only occur if the candidate workstation is either at the start or the end of the line. Elimination of any other workstation creates the possibility of gaping holes in cases where unmovable workstations exist. Since the elimination of workstations is in most cases unpractical, then the objective of assembly line balancing should be that of workload equalization among the given workstations. This objective makes sense considering that the line cycle time is almost exclusively given by the company's marketing department. In other words, consideration for decreasing the cycle time should only be entertained in cases where the cycle time exceeds targets set up by marketing. Other practical constraints that are often ignored in SALBP include the uses of multiple operator operations at one station, implying that the lead time for such a workstation becomes the time for the slowest worker. Some operations require more than one operator to be carried out. A typical operation would be the mounting of a bumper which may require two operators, one at each end. Ergonomics constraints should also be made an important part of assembly line balancing. A good discussion of how ergonomic considerations are an important component that should be made an integral part of assembly line balancing constraints is discussed in (Falkenauer, 2005). In this project we discuss the development of a practical hands on lab for teaching line balancing in an undergraduate manufacturing course.

4.4 Developing a Practical Assembly line balancing problem for manufacturing system course (INSY 3800)

Manufacturing systems 1 course (INSY 3800) is an industrial engineering course offered in the spring Semester at Auburn University's . The average size for this class is 90 students composed mainly of sophomore, junior and a few senior students. This course has a lab component which requires students to attend a 3 hour lab each week . Students were randomly assigned to a team of no more than 10 members. Each team was then assigned to a manufacturing cell (See figure 4.2 on page 62 for the purposes of simulating the operations of a manufacturing assembly line). The assembly plant model is a mixed model assembly plant that assembles 2 models of vehicles as shown in figure 4.1. Each team was allocated a manufacturing work cell whose workstations are characterized by unbalanced workloads (See Figure 12, page 59). Each team will be led by a team leader who will be responsible for coordinating the activities of the cell. Unlike line balancing problems found in textbooks, this line balancing problem is a more realistic problem similar to real world balancing problems. Contrary to textbook formulated line balancing problems, there are additional tasks that are required to be successful in carrying out the exercise. These additional tasks provide students with good practical experience on how to approach a real world problem and how to solve it. In order for students to have an appreciation of the line balancing problem and how it relates to real world line balancing problems, the following steps were designed into the lab.

1. Participate in live simulated production run (Production run 1) and record line performance metrics.

2. Establish standard times using stop watch time study or any the predetermined time motion studies (PTMS).

3. Establish precedence constraints from assembly charts.

4. Establish resource and zoning constraints by taking into consideration design for assembly (DFA) and (DFM) principles.

5. Using Line balancing heuristics solve the line balancing problem, and establish theoretical line balance metrics.

6. Using LegoCad software (MLCad) edit the work instructions to reflect changes to the work instructions as necessitated by new line balance solution.

7. Team leader coordinates training on the rebalanced using

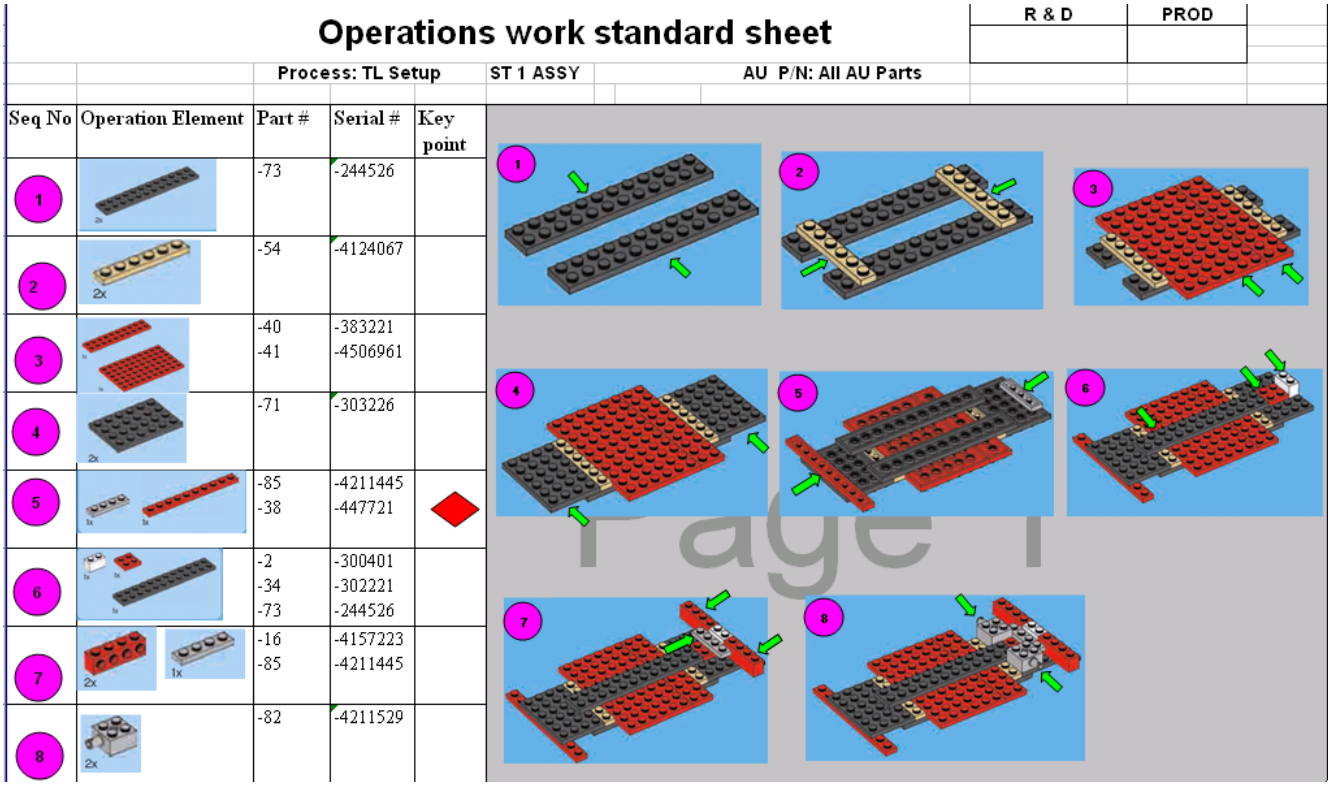
8. Conduct a 1 hour production run (Production run 2) and record data that allow for evaluation of system performance.

9. Participate in continuous improvement meeting and make adjustment to the line

10. Participate in a final production run (Production 3) and record data that allows for evaluation of system performance.

The steps above were carried out over a period of 3 separate lab sessions . To initiate the assembly line balancing problem, an initial unbalanced line was presented to students. At this particular stage, students had no prior experience with any of the operations of the manufacturing cell that they had been assigned to. The objective for each group was to meet a production rate of 51 units/hour, implying a Takt time of 70 seconds. For this goal to be achieved students were required to use a combination of industrial engineering tools/techniques to establish system inadequacies and subsequently make changes that would achieve the desired goal. Assembly line balancing was found to be one among many other applicable IE tools relevant to the situation. Other IE tools considered included, value stream mapping, cell design strategies, ergonomic analysis applied to workstation design, and single minute exchange of dies. The two products used for assembly line balancing are Lego products and can be easily purchased from Lego on-line store. The products are shipped with an assembly instructions booklet that details the steps required for assembling the product. The assembly instructions are also available in PDF format loadable from the Lego on line store. It is important to note the sequence of steps presented in the original Lego assembly manual are in many cases not the most efficient way of assembling the product from a line balancing perspective . This inadequacy in the original Lego product assembly instruction was used to formulate a practical line balancing problem. The sequence of assembly steps were re-evaluated using a line balancing heuristics that were part of in-class learning.

Figure 4.16 shows the original subset of steps (16% of total work) required to assemble the Speeder vehicle. To achieve the full assembly, 48 of these steps are required. The assembly steps are spread over three departments (Manufacturing cells) as discussed earlier. In assembly line balancing, the separate and distinct steps are referred as work elements. In most cases, it is the responsibility of IE to determine what should consist of work elements in any assembly operation. However, there are rules of thumb that can be followed in establishing the work elements associated with any assembly work. For this project it was decided that each of the original steps provided in the OEM assembly manual be considered



Operations work standard sheet

R & D	PROD

Process: TL Setup | ST 1 ASSY | AU P/N: All AU Parts

Seq No	Operation Element	Part #	Serial #	Key point
1	2x	-73	-244526	
2	2x	-54	-4124067	
3		-40 -41	-383221 -4506961	
4	2x	-71	-303226	
5	1x 1x	-85 -38	-4211445 -447721	◆
6	1x 1x 1x	-2 -34 -73	-300401 -302221 -244526	
7	2x 1x	-16 -85	-4157223 -4211445	
8	2x	-82	-4211529	

Figure 4.16: OEM assembly instructions

a work element since most of the steps met the rule of thumb used for defining elements. Taking this in consideration, it can be seen that Figure 4.16 shows elements 1 through 8. An important input to the assembly line balancing problem is the standard task time determined for each work element. This is the time it takes to complete each defined work element. The students were therefore required to undertake a stopwatch time study to establish the standard times for each work element.

4.4.1 establishing standard times (T_{ek}) for elements

Denoting (T_{ek}) to be the task time for element k, it is necessary to determine all task times through a stop watch time study. Students were presented with a video of an experienced operator performing assembly work at each of the respective stations (stations 1 through station 15). Verbal instructions as well as written instructions were provided, detailing how stopwatch time study is done. Working in groups of two, students watched the video and used a stopwatch to establish the elemental times for associated tasks. This exercise was essential in demonstrating how time standards are established. A form used for recording the elemental times and computing the associated standard time for each station is provided in the appendix.

Manager

Team Leaders	**Designated Area /Responsibility**
Ali Aldubaisi	
Kamran Kardel	
Emin Ciftci	

Station Operators

Station Number	**Operator Assigned**	
	Operator 1	**Operator 2**
	Carter Astin	

Material Handler

Quality Controller

Department:	**Station: 1**	**Study No:**
Model:		**Sheet No:**
Operation:		**Time off:**
Plant/Machine:		**Time on:**
Tools and Guages:		**Elapsed Time:**
		Operative:
Product/Part:		**Clock Number:**
DWG No:		**Studied by:**
Quality:		**Date:**
		Checked by:

		Speeder														
		Observed time														
El. No.	**El Description**	**Carter Astin** 1	2	3	4	5	6	7	8	9	10	**Total OT**	**Ave-rage**	**R**	**BT**	**NT**
1		2	1.64	0.53	1.43	1.08	10.02	10.62	9.95	10	10.01	57.28	5.728	1	5.728	6.24352
2		9.53	10.64	9.84	7.35	6.42						43.78	8.756	1	8.756	9.54404
3		7.25	10.5	8.01	5.11	6.96	11.68	12.85	11.78	11.1	11.3	96.54	9.654	1	9.654	10.5229
4		8.47	5.5	5.06	6.24	7.3	7.58	6.79	6.9	6.5	7.01	67.35	6.735	1	6.735	7.34115
5		15.27	7.54	7.71	8.21	9.01	9.1	6.49	7.1	7.9	8.23	86.56	8.656	1	8.656	9.43504
6		14.57	15.71	13.3	11.42	10.48	8.88	8.9	8.5	7.6	7.9	107.26	10.726	1	10.726	11.6913
11		24.49	27.04	21.23	21.36	22.02	22.3	18.72	18.9	19	18.89	213.95	21.395	1	21.395	23.3206
																78.1

		SUV														
		Observed time														
		Carter Astin 1	2	3	4	5	6	7	8	9	10	**Total OT**	**Ave-rage**	**R**	**BT**	**NT**
201		1.65	1.26	1.34	1.33	1	15	17.2	13.47	14.31	13.1	6.58	1.316	1	1.316	1.43444
202		3.88	5.9	6	4.67	5.82						26.27	5.254	1	5.254	5.72686
203		7.72	4.62	4.44	6.5	9.5						32.78	6.556	1	6.556	7.14604
204		9.85	5.54	5.67	6.62	8.7	6.85	8.43	5.32	6.5	5.5	36.38	7.276	1	7.276	7.93084
205		12.29	12.96	8.43	10.45	5.45	7.35	7.37	5.23	8.94	7.12	49.58	9.916	1	9.916	10.8084
206		25.43	27.74	33.99	24.56	20.93	45.93	36.47	27.1	25.1	25	132.65	26.53	1	26.53	28.9177
																61.96

R: Rating OT: Observed time BT: Basic Time NT: Normal time

allowances Summary	
Personnel needs	4
Basic Fatigue	5
Variable Fatigue	
Special	
Total Allowance	**9**

Station1-ST / Station 2-ST / Station 3-ST / Station4-ST / Station4-2-ST / Station5-ST / Station-6-ST / Station-7

Figure 4.17:

4.4.2 Conducting the line balancing lab

The line balancing lab is done in one lab session. This lab is is in the form of a structured lab where students were introduced to the line balancing algorithm associated with heuristics selected to taught in the lab. The actual line balancing was formulated in Excel, and will be discussed in more detail. The three heuristics considered for this exercise included the following, all of which are part of classroom learning material:

- Ranked positional weight method (RPW)
- Largest candidate rule (LCR)
- Kilbridge and Wester method (KWM)

The above listed heuristics are part of classroom learning and are all subject to testing during scheduled quizzes and exams. The RPW heuristic was selected to be used in the lab based on its superiority performance compared to the other two listed heuristics. The RPW method combines both attributes of the LCR and KVM since it takes into account the service time at a station as well as position in the precedence diagram of an element.

Step 1: Determine RPW values of each element/task in the precedence table The first step in the RPW method is completing a precedence table. This table details the order in which elements/tasks precede each other in the sequence of operations. The precedence table is established by analyzing the assembly instruction (see figure 4.16) and determining the order in which parts are put together. It is important to note that only immediate predecessors are the only necessary relationship between elements that we are concerned with at this stage of the problem. In this particular case it can be seen that element 1 should precede 4 and element 4 should precede element 5. There is no need to include element 1 as a predecessor of 5, as it is automatically implied. Figure 4.19 shows a partial table showing the precedence of tasks/elements for the speeder vehicle. In the lab, students were presented with an incomplete precedence table and they were expected to complete the table by analyzing the assembly instructions. The highlighted cells in figure 4.19 are left blank so that students can complete as part of lab tasks for that day. The complete table and assembly manual are given in appendix D.

Cell 1 Precedance Table

Ope #	Work element Description	Serial #	Part #	Quntity	Tek(seconds)	Must be Preceded by Operation #	Station	Station Cycle Time (s)
1	place the two parts side by side	244526	73	2		-		
2	Assembly part as shown in in 2	4124067	54	2		1		
3	Assembly part as shown in in 3	383221	40	1		1		
		4506961	41	1				
4	Assembly part as shown in in 4	303226	71	2		1		
5	Flip Assembly and attach parts as show	4211445	85	1		4		
		447721	38	1			1	
6	Assembly part as shown in in 6	300401	2	1		2,3,4		
		302221	34	1				
		244526	73	1				
7	Assembly part as shown in in 7	4157223	16	2		4,6		
		4211445	85	1				
8	Assembly part as shown in in 8	4211529	82	2		4		

Figure 4.18: Partial Precedance table for Speeder vehicle

The completion of the precedence table leads to the drawing of a precedence diagram. The precedence diagram is drawn from observing the relationships between elements in the precedence table. The precedence diagram specifies the order or sequence in which activities must be performed. Figure 4.19 shows a completed precedence table for manufacturing cell-1. In the lab students were presented with an incomplete precedence diagram and their task was to establish the relationship between the remaining elements. Because we have 2 products, two precedence diagrams are required for each manufacturing cell. The completed precedence diagrams required for all cells are given in appendix D.

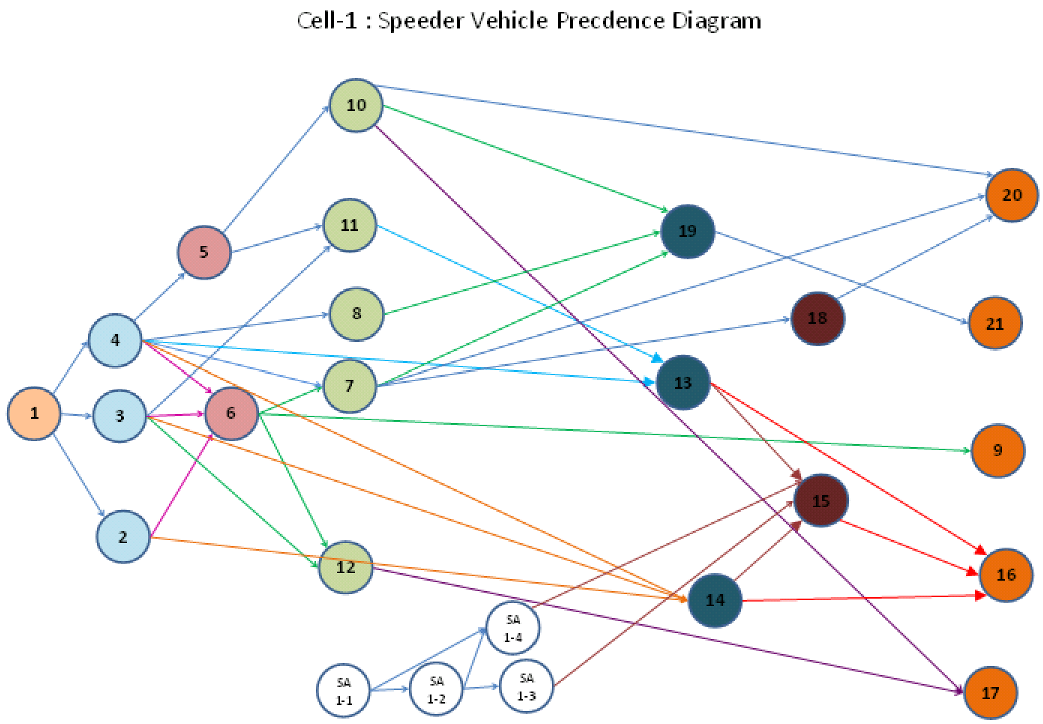


Figure 4.19: Precedence Diagram for Speeder vehicle

Step 2: Determine RPW values of each element/task in the precedence table A complete precedence table allows for the calculation of RPW values of all elements/tasks in the precedence table. If we denote RPW_k as the RPW value for element k then RPW_k is calculated by summing T_{ek} and all other times for elements that follow T_{ek} in the arrow chain of the precedence diagram. With reference to figure 4.19, the RPW values of each element are calculated in the following manner

$$RPW_5 = T_{e5} + T_{e10} + T_{e11} + T_{e13} + T_{e15} + T_{e16} + T_{e17} + T_{e19} + T_{e20} + T_{e21}$$

$$RPW_6 = T_{e6} + T_{e7} + T_{e9} + T_{e12} + T_{e17} + T_{e18} + T_{e19} + T_{e20}T_{e21}$$

Because the above procedure of determining RPW values can can be tedious and error prone, an excel formulation was done to automate the process. A precedence matrix was formulated to calculate all RPW values for all elements in the precedence diagram (see Figure 4.1 .

Y4 =B4+MMULT(D4:X4,Ti)

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1			Precedence Matrix																					
2			Operation number (K)																					
3	T_{ek} (sec)	K	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	RPW
4	3.90	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	317
5	9.06	2	0	0	0	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	220
6	8.28	3	0	0	0	0	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	245
7	6.52	4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	295
8	8.50	5	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	1	189
9	12.89	6	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	1	1	133
10	10.09	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	71
11	5.73	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	30
12	3.61	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
13	15.80	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	74
14	19.60	11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	107
15	11.06	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	23
16	8.81	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	87
17	19.16	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	32
18	65.86	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	78
19	12.40	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
20	11.76	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
21	36.92	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
22	11.56	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	24
23	22.42	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
24	12.65	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
25	T_{wc}	317																						

Figure 4.20: Precedence matrix displaying the relationship between elements

In figure 4.1, column (C4:C24) and row (D3:X3) shows the tasks required to complete the assembly in Cell 1. The relationship of an element in column (C4:C24) and any of the elements in row (D3:X3) is indicated by placing a 1 or 0 in the cell intersecting the two tasks. A 1 indicates the presence of a dependency relationship between two elements, while a 0 indicates that the two elements in question are independent of each other. Looking at figure 4.1 it can be deduced that tasks/elements {6,7,9,12,15,16,17,19 and 21} have a dependency relationship with element 1, i.e. task 1 must precede the the listed tasks. Column (Y4:Y24) shows the RPW values for each task. This value is obtained by multiplying the appropriate row in (D4:X24) by column (C4:24) plus appropriate task time (T_{ek}). RPW_1 is shown in cell X and the formula used to calculate it , X4=B4+MMULT(D4:X4,Ti) shown in the formula bar. Applying this formula to all cells in column Y will yield the RPW values for all other tasks as indicated in figure 4.1.

Table 4.1: Precedence matrix displaying the relationship between elements

Y4 =B4+MMULT(D4:X4,Ti)

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1			Precedence Matrix																					
2			Operation number (K)																					
3	T_{ek} (sec)	K	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	RPW
4	3.90	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	317
5	9.06	2	0	0	0	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	220
6	8.28	3	0	0	0	0	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	245
7	6.52	4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	295
8	8.50	5	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	1	189
9	12.89	6	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	1	1	133
10	10.09	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	71
11	5.73	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	30
12	3.61	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
13	15.80	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	74
14	19.60	11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	107
15	11.06	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	23
16	8.81	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	87
17	19.16	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	32
18	65.86	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	78
19	12.40	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
20	11.76	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
21	36.92	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
22	11.56	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	24
23	22.42	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
24	12.65	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
25	T_{wc}	317																						

Step 3: Assign elements to tasks in accordance to RPW criterion

Table 4.2 shows results of sorting table 4.1 in descending order of RPW. Using table 4.1, students are then required to follow RPW criterion in assigning tasks to stations. As each element is assigned the appropriate row is crossed out, as shown in 4.2 to indicate it has been eliminated as a candidate element for the next assignment. An assignment table is used to aid the assignment process (see figure refAssignment). The iterative procedure for assigning elements to stations using RPW criterion is as follows:

step I Starting with task with the largest RPW value, we assign it to the first station, if it satisfies the precedence constraint and does allow the total sum of T_{ek} to exceed the

Table 4.2: RPW values sorted in descending order

		RPW Values sorted in Descending Order																					
Tek (sec)	OP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	RPW
3.90	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	317
6.52	4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	295
8.28	3	0	0	0	0	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	245
9.06	2	0	0	0	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	220
8.50	5	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	1	189
12.89	6	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	1	1	133
19.60	11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	107
8.81	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	87
65.86	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	78
15.80	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	74
10.09	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	71
36.92	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
19.16	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	32
5.73	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	30
11.56	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	24
11.06	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	23
22.42	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
12.65	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
12.40	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
11.76	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
3.61	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
316.58																							

allowable Takt time. If an element is selected, cross it out from the list of available elements and consider an element with the next largest RPW value.

stepII When no more elements can be selected, proceed to the next station.

step III repeat step I and step II for the remainder of the stations until all have been assigned

		RPW Values sorted in Descending Order																					
Tek (sec)	OP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	RPW
3.90	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	317
6.52	4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	295
8.28	3	0	0	0	0	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	245
9.06	2	0	0	0	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	220
8.50	5	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	1	189
12.89	6	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	1	1	133
19.60	11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	107
8.81	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	87
65.86	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	78
15.80	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	74
10.09	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	71
36.92	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
19.16	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	32
5.73	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	30
11.56	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	24
11.06	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	23
22.42	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
12.65	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
12.40	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
11.76	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
3.61	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
316.58																							

Table 4.3 is used as a decision support system that aids in the decision process associated with assigning tasks to stations. The students are however expected to be aware of the rules governing the assignment of tasks. Using Column D, the students assign a task to a station and automatically the table populates the other cells in the same row with data, which the students can then interpret to make an informed decision regarding whether the current element is a feasible assignment. The immediate predecessor column shows what elements should precede the current assignment, while cumulative time shows the sum of T_{ek} that have been assigned to that station. The unassigned column is a very important column as it indicates the maximum task time that can be accommodated at that station in the next assignment.

Table 4.3: Decision support table for assigning tasks to stations

Takt time (sec)	70
Ideal Cycle (sec)	63
Set Cycletime (sec)	65
Allowable variance	-5

Assigment of Operations to Work-Stations

Station (j)	Op (k)	RPW	Immediate predecessor	T_{ek}	Cumulative time (sec)	Unassigned time (sec)	Remarks
1	1	317	-	3.90	4	66	
1	4	295	1	6.52	11	59	
1	3	245	1	8.28	19	51	
	4	295	1	6.52	25	45	
	5	189	4	8.50	34	36	
	6	133	2,3,4	12.89	47	23	
	11	107	3,4,5	19.60	66	4	
2	7	71.2	4,6	10.09	10	60	
2	8	29.9	4	5.73	16	54	
2	9	3.61	6	3.61	19	51	
2	10	74.2	3	15.80	35	35	
2	13	87.1	4,11	8.81	44	26	
2	14	31.8	2,3,4	19.16	63	7	
3	15	78.3	13,14	65.86	66	4	
4	12	22.8	3,6	11.06	11	59	
4	18	36.9	7	36.92	48	22	
4	19	24.2	6,7,8,10	11.56	60	10	
5	16	12.4	13,14,15	12.40	12	58	
5	17	11.8	12,13	11.76	24	46	
5	20	22.4	7,10,18	22.42	47	23	
5	21	12.7	19	12.65	59	11	
			T_{WC}	314			

It is also important to note that the objective of this line balancing problem is equalization of workload across workstation, thus the use of 65 seconds rather than the Takt time of 70 seconds as the target station cycle time at each station. Table 4.3 shows the complete line balance using the RPW method for speeder vehicle for Cell-1. In a similar manner, line balancing was carried out for all manufacturing cells for both the speeder and SUV vehicles and the results of these endeavors are presented in appendix LBSolution

Evaluating the theoretical line balance solution

Once a line balance solution has been obtained it is necessary to evaluate how good the solution is. In this project, two metrics were used, (1) line balance efficiency (E_B) and (2) Line balance delay (E_D)

$$E_B = \frac{T_{WC}}{nT_S} \tag{4.4}$$

$$E_d = \frac{nT_S - T_{Wc}}{nT_S} \tag{4.5}$$

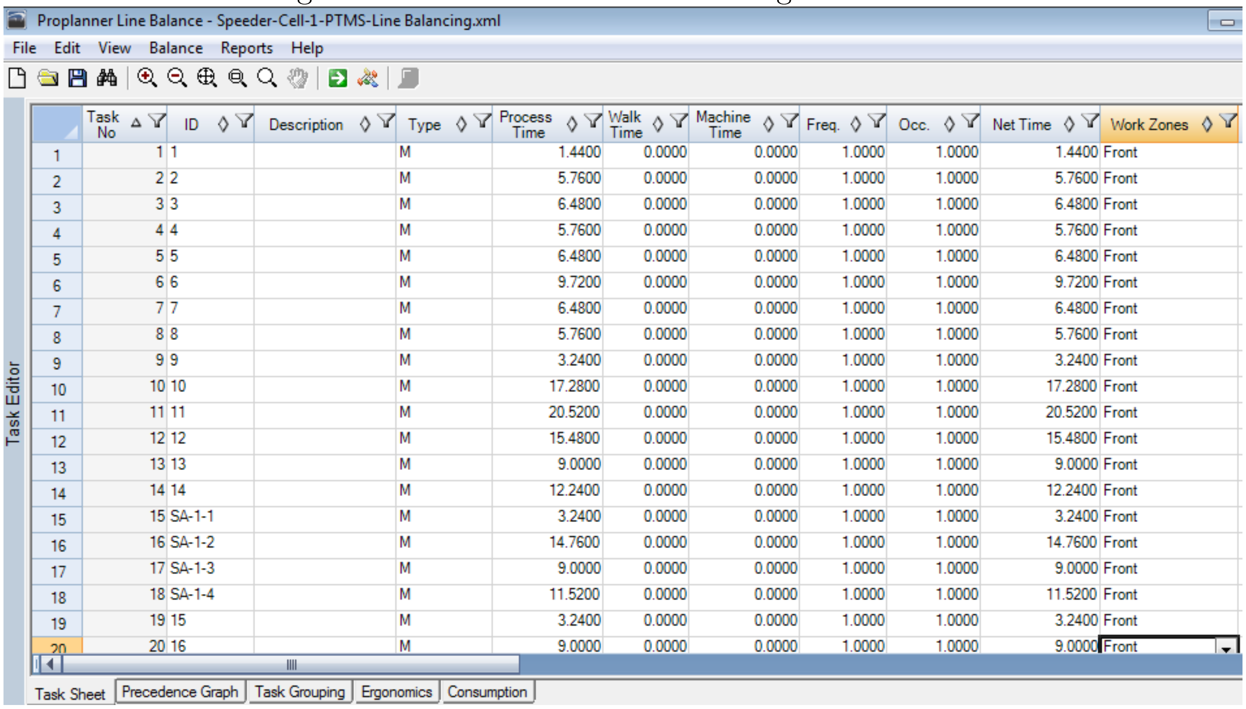
Where T_{WC} is the total work content,e T_S is the maximum service time among all stations in the cell, i.e. the bottleneck service time and n is the number of workstations in the cell. The closer E_B is to 1, the better the line balancing solution is. E_D indicates the percentage of time lost due to an unbalanced line. A good line balance solution is one with large value of E_B and small value of E_D.

4.5 Using computerized line balancing software for teaching line balancing

Pro-planers ProBalance software is one of a few commercial ALB softwares available for assembly purposes. The software can be used for both single model and mixed model assembly lines. Pro-balance allows ease of handling of constraints compared to manual ALB. The software allows for the handling of more constraints than can possibly be done using manual assembly methods described earlier. Constraints such as work zones, resource oriented constraints, multi-operator constraints, as well as ergonomic constraints can be handled more efficiently using a computerized method such as Probalance. To afford students the opportunity to use a commercial line balancing software, Probalance software was used in the lab for line balancing. While stop watch standard time data was used as input to the manual line balancing method, predetermined standard task times were used with the Probalanced software. Both models (Speeder and SUV) were balanced using Probalance for all cells (Cell-1, Cell-2, and Cell-3)

The first stage of using Probalance software involves entering data on a task sheet. Each row in the task sheet is an activity (or task). In each row in the task sheet a task ID and process time is entered. Other columns on this sheet are for additional information that the user could use as desired, table 4.4. The table shows the task sheet for the the assembly of Speeder vehicle in Cell-1

Table 4.4: stage 1: Probalance task sheet showing task ID and task times



Proplanner Line Balance - Speeder-Cell-1-PTMS-Line Balancing.xml

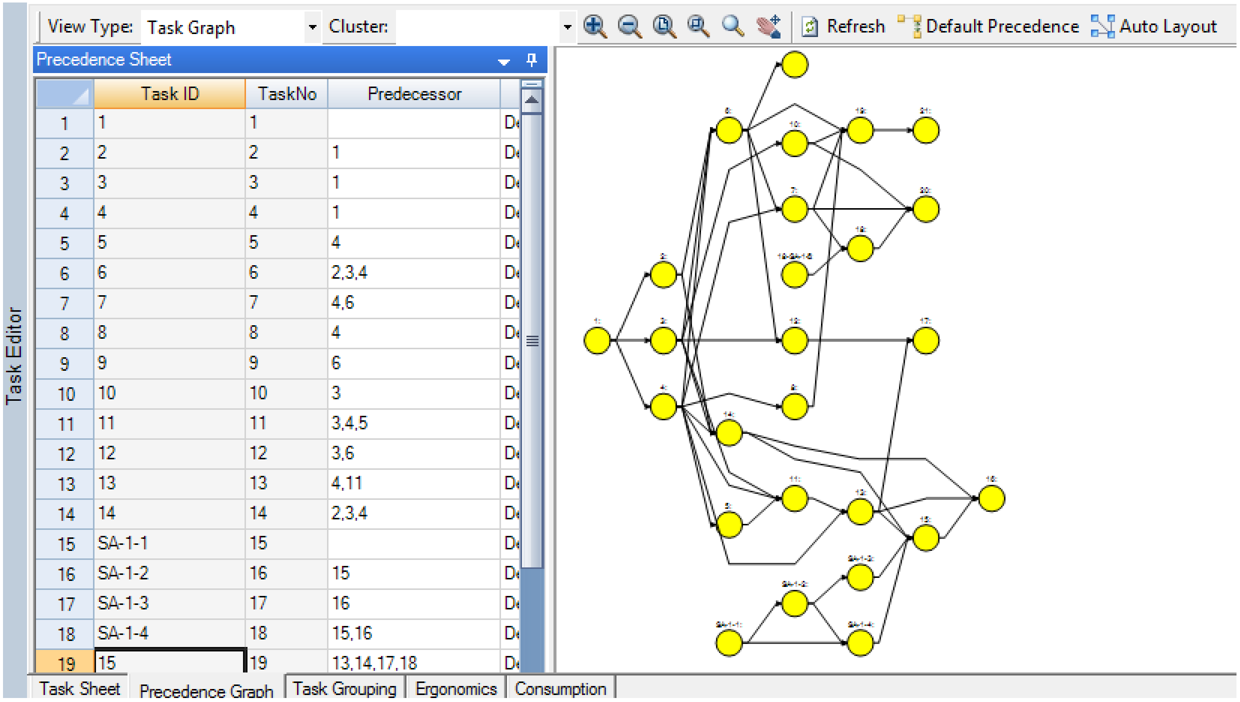
File Edit View Balance Reports Help

Task Editor

	Task No	ID	Description	Type	Process Time	Walk Time	Machine Time	Freq.	Occ.	Net Time	Work Zones
1	1	1		M	1.4400	0.0000	0.0000	1.0000	1.0000	1.4400	Front
2	2	2		M	5.7600	0.0000	0.0000	1.0000	1.0000	5.7600	Front
3	3	3		M	6.4800	0.0000	0.0000	1.0000	1.0000	6.4800	Front
4	4	4		M	5.7600	0.0000	0.0000	1.0000	1.0000	5.7600	Front
5	5	5		M	6.4800	0.0000	0.0000	1.0000	1.0000	6.4800	Front
6	6	6		M	9.7200	0.0000	0.0000	1.0000	1.0000	9.7200	Front
7	7	7		M	6.4800	0.0000	0.0000	1.0000	1.0000	6.4800	Front
8	8	8		M	5.7600	0.0000	0.0000	1.0000	1.0000	5.7600	Front
9	9	9		M	3.2400	0.0000	0.0000	1.0000	1.0000	3.2400	Front
10	10	10		M	17.2800	0.0000	0.0000	1.0000	1.0000	17.2800	Front
11	11	11		M	20.5200	0.0000	0.0000	1.0000	1.0000	20.5200	Front
12	12	12		M	15.4800	0.0000	0.0000	1.0000	1.0000	15.4800	Front
13	13	13		M	9.0000	0.0000	0.0000	1.0000	1.0000	9.0000	Front
14	14	14		M	12.2400	0.0000	0.0000	1.0000	1.0000	12.2400	Front
15	15	SA-1-1		M	3.2400	0.0000	0.0000	1.0000	1.0000	3.2400	Front
16	16	SA-1-2		M	14.7600	0.0000	0.0000	1.0000	1.0000	14.7600	Front
17	17	SA-1-3		M	9.0000	0.0000	0.0000	1.0000	1.0000	9.0000	Front
18	18	SA-1-4		M	11.5200	0.0000	0.0000	1.0000	1.0000	11.5200	Front
19	19	15		M	3.2400	0.0000	0.0000	1.0000	1.0000	3.2400	Front
20	20	16		M	9.0000	0.0000	0.0000	1.0000	1.0000	9.0000	Front

Task Sheet | Precedence Graph | Task Grouping | Ergonomics | Consumption

Table 4.4 shows the task entry for the speeder vehicle in Cell 1. As shown, the tasks are entered as a task ID and then the processing time for each station is entered. The work zone column allows us to define workzone constraints associated with a task. A good example would be a fuel tank located on the left side of vehicle , thus requiring that such a task be assigned a left zone working constraint. The task sheet also allows for defining resource constraints. Resource could be reconfigurable or monumental, implying that they are fixed at a particular station. Once all the necessary entries have been entered, the user precedes with defining precedence constraints using the precedence sheet shown in figure 4.21. In a similar manner to defining precedence constraints using the manual method, the user defines the immediate predecessor for each task. As the precedence for each task is inputed, the software automatically generates a precedence diagram shown in 4.21 . There may be cases in which it is required that particular tasks be installed at the same station. This is accomplished through a feature of the software that allows tasks grouping whose tab is shown in table 4.4 .



	Task ID	TaskNo	Predecessor
1	1	1	
2	2	2	1
3	3	3	1
4	4	4	1
5	5	5	4
6	6	6	2,3,4
7	7	7	4,6
8	8	8	4
9	9	9	6
10	10	10	3
11	11	11	3,4,5
12	12	12	3,6
13	13	13	4,11
14	14	14	2,3,4
15	SA-1-1	15	
16	SA-1-2	16	15
17	SA-1-3	17	16
18	SA-1-4	18	15,16
19	15	19	13,14,17,18

Figure 4.21: Stage 2: Establishing Precedance in Probalance software

Figure4.21 shows precedence formulation in Probalance software. Minimizing the number of stations was the stated objective used in the line balancing algorithm. Figure 4.22 shows the chart for cell 1. The line balance efficiency using Probalance E_B was found to be equal to 91% , while the manual LB method discussed in section 4.4 on page 80 had a theoretical Lb efficiency of 89%. It is important to keep in mind that while manual line balancing problem used stop watch standard time data as input, the most predetermined

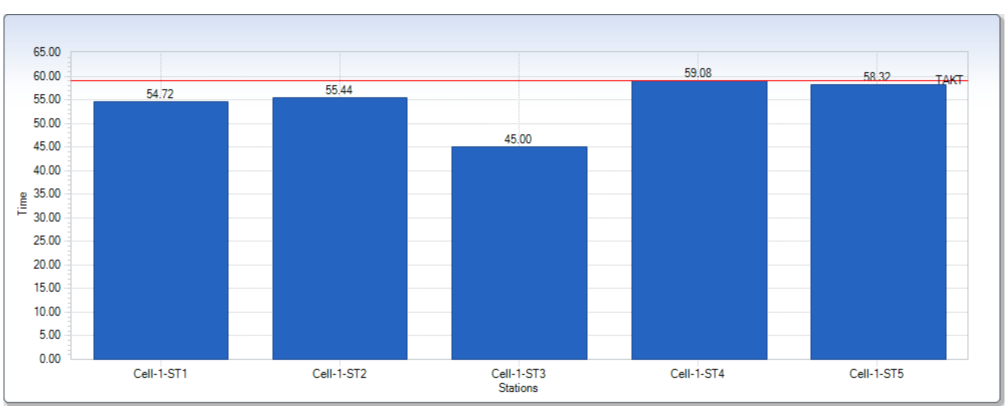


Figure 4.22: Stage 3: Evaluated line balance using Probalance software

time standards were used as input to the Probalance software. While stopwatch time study data is stochastic, taking into consideration the presence of both within operator variation and between operator variation , predetermined time standards are deterministic. Because of these differences, a research question thus arises with regard to the use of standard time in assembly line balancing:

Does the method used for generating standard time data in assembly line balancing have an impact on the quality of the line balancing solution.

The quality of the line balancing solution in this instance refers to the desired line balance metrics (E_B) obtained from actual data. To help answer the question a hypothesis was formulated as follows.

Hypothesis Using Predetermined time standards (MOST) as input to the assembly line balancing problem will yield to a superior validated assembly line balancing solution than using operation standard times established from stop watch time study.

	Line balance using Stopwatch standard time data as input														
	Cell-1					Cell-2					Cell-3				
	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-7	ST-8	ST-9	ST-10	ST-11	ST-12	ST-13	ST-14	ST-15
T_C Stop Watch	58.93	61.24	64.97	51.97	52.62	57.28	65.56	63.15	61.64	59.67	59.35	60.68	66.76	65.39	68.20
T_C PMTS	50.98	50.98	49.68	56.38	47.45	45.79	50.98	57.27	39.96	46.87	56.02	48.24	58.18	38.09	68.73
E_B stopwatch	0.89					0.94					0.94				
E_BPMTS	0.91					0.84					0.78				

(a) StopWatch Line balance solution metric

	Line balance using Predetermined standard time data as input														
	Cell-1					Cell-2					Cell-3				
	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-7	ST-8	ST-9	ST-10	ST-11	ST-12	ST-13	ST-14	ST-15
T_C Stop Watch	60.62	52.17	53.95	85.02	59.39	61.84	69.29	57.78	64.09	54.12	57.63	59.18	44.50	52.34	52.49
T_C PMTS	49.34	49.68	53.38	57.02	49.61	50.69	57.17	48.89	40.25	46.75	53.86	58.18	50.15	52.34	54.47
E_B stopwatch	0.73					0.89					0.90				
E_BPMTS	0.91					0.85					0.92				

(b) Predetermined line balance solution metrics

Figure 4.23: Comparing stopwatch standard time data and PMTS standard time data as input to in assembly LB problem.

For each station shown in figure 4.32, two theoretical station cycle times $E_B Stopwatch$ and $E_B PMTS$ were established. Taking station 1 in figure 4.33(a) as an example, the station cycle time can be considered to be 58.93 seconds if stopwatch data is considered and 50.98 seconds if PMTS standard data is considered. The question thus is, given a choice between the two standard time data outlined, which times should be selected to be input in an assembly Lb problem. Figure 4.33(a) shows the results of balancing the assembly line using stop watch standard time data as input, while figure 4.33(c) is the line balance solution using PMTS standard time data input. For each generated solution, the associated $E_B Stopwatch$ and $E_B PMTS$ was established. From Figure 4.32 it is evident that balancing a line using stopwatch standard data as input yields favorable E_B values for all cells, the associated E_B values obtained with PMTS data is not always favorable as seen by not so desirable E_B values of 0.78 for cell 3. The same can be said for line balance solutions generated using PMTS standard time data as input. Because of this conflict, thus the research question.

4.5.1 A comparison of stopwatch time study and Predetermined times in manual assembly task

Assembly task times are an important input in assembly line balancing. These task times can be established by either stop watch time study or Predetermined motion and time study methods (PMTS), such as MOST, Modapts, MTM among a host of other predetermined time systems. It is the believed that the accuracy of assembly task times used in assembly line balancing problems may have a significant impact on the quality of the line balancing solution. In this section we compared assembly task times established through stopwatch time study, PMTS method and the actual service times taken during simulated production run. The task times established through either method were then used as input to an assembly line balancing problem (LB) to yield two different assembly line balancing solutions.

The two solutions were then implemented in live simulated production runs and results were compared to the theoretical line balance solution.

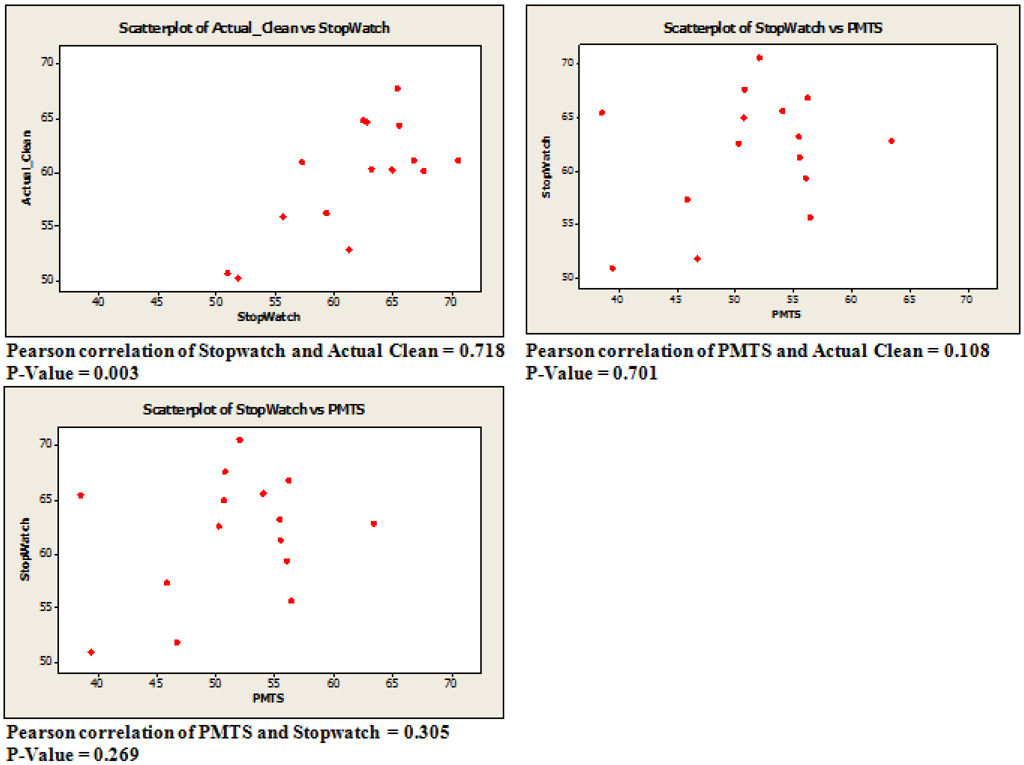


Figure 4.24: Scatter plots for establishing correlations of standard times with actual service times for manual balanced assembly line

Figure 4.24 shows the relationship between the standard times established using stopwatch time study and MOST Predetermined times standards with actual service times observed during simulated production runs. The biggest correlation was obtained with stopwatch time study (pearson correlation coefficient of 0.718) while PMTS standard times showed a low correlation (pearson correlation coefficient of 0.108). The correlation between PMTS and stopwatch study was low (pearson correlation coefficient of 0.315). Considering this low correlation between stopwatch time study and Predetermined motion time standard, it brings into question how the choice time standard selected to be input in line balancing problem affects the accuracy of the results.

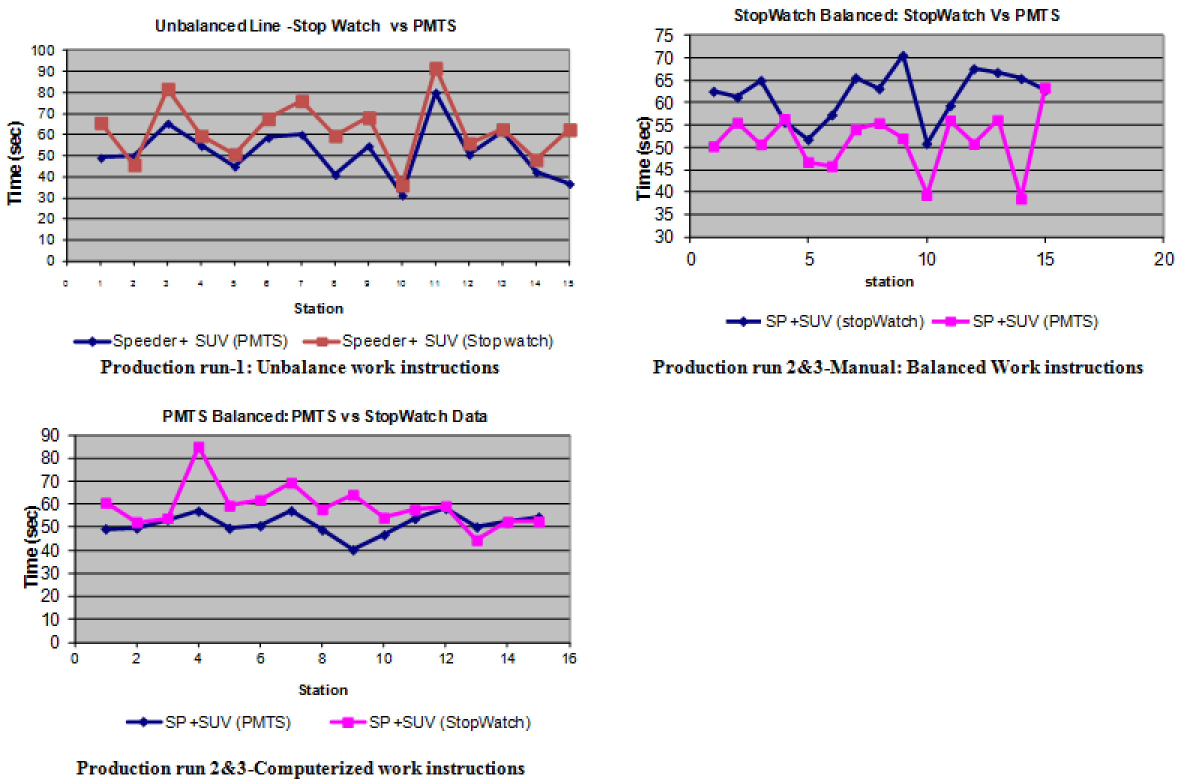


Figure 4.25: Comparison of stopwatch standard times Vs Predetermined times

Figure 4.25 shows the comparison of standard times obtained using stopwatch time study and predetermined time study method (MOST) for three different assembly work instructions. The correlation between two standard times was tested. Only the unbalanced work instructions showed high correlation while the balanced work instructions showed low correlation (< 0.5).

Production run-1

The first production run (Production run-1) used the initial setup which simulated an unbalanced production run. This production run was meant to bring awareness of the problems that may exist as far as running the cell is concerned. Prior to this lab, students had participated in a time study lab during which they were required to calculate theoretical line balance metrics E_b and E_d using the data collected. Using standard time data collected from the time study lab, a theoretical line balance chart for each cell was constructed, figure ??.

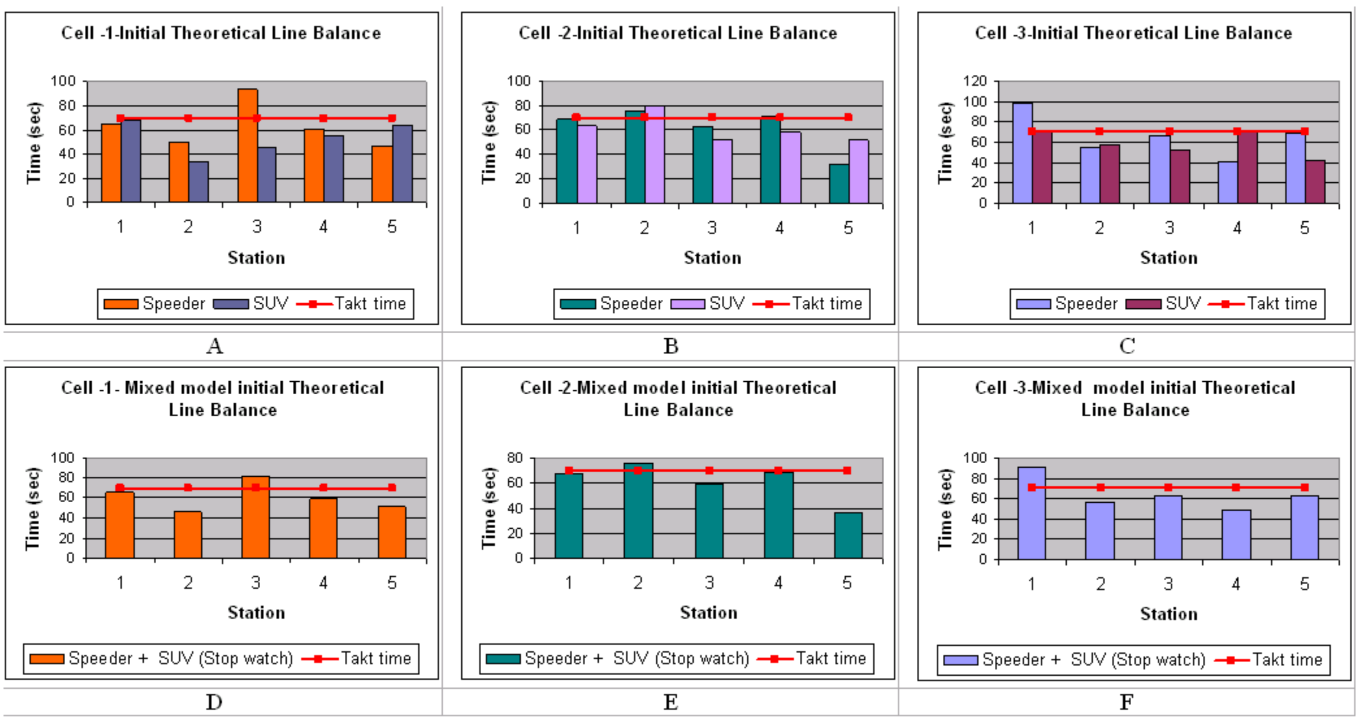


Figure 4.26: Unbalanced line line balance sheets

Table 4.5 shows the theoretical line balance metrics for the three cells at Tiger Motors. It is evident that there is imbalance of work within each cell, as well as between cells.

With the current setup, it is apparent that students assigned to cell-1 were expected to face difficulties ensuring that the downstream cell- 2 is was not starved of parts. In a similar manner, if no restrictions on the build up of work in process (WIP) is put in

Table 4.5: theoretical initial line balance metrics

	Initial line balance Metrics		
	Cell1	Cell 2	Cell 3
E_B	74%	81%	70%
E_D	26%	19%	30%
R_{pExp} Units/hr	44	47	39

place, then a buildup of WIP is expected between cell-2 and cell-3. This scenario presented a significant opportunity for demonstrating various concepts in manufacturing systems and lean manufacturing. This was the initial setup that was presented to students in the first live simulated run. This initial setup was intentionally presented so that students participating in the lab would experience problems and thus fall short of their target output. In order for students to track their performance, it was essential that production related data be collected during the simulation run.

4.5.2 Data collection during the lab

Data collection is an important aspect of the lab as it allows students to analyze the performance of the system after each live simulation run. For the INSY 3800 course, there was a need to collect data that would allow students to determine the throughput metrics as well as station related data. The station service time (T_{si}) as well as non-value added (NVA) times at each station were important components as these would enable students to identify problem areas and determine line balance metrics. To facilitate ease of data collection, two data collection forms were created , namely: (1) throughput data capture form and (2) Value added/None value added form).

Throughput data capture form

This form was created to capture data related to the throughput of the system. Each manufacturing cell needs two of these forms. One form is used at the entry point (First station) of the cell to record a time stamp for each unit that begins to be processed in the cell. The other form is used at the Exit point (last station) of each cell to record the time that each completed unit leaves the station. Figure 4.6 shows an example of throughput data capture form. The full form and instructions on how this form is used is given in appendix C

Table 4.6: Capturing throughput time data

Throughput Data Capture Table

	Stop Watch Number:				
	Station (Entering):	Station 6			
	Watch Operator:	Taylor Owens			
	Car Number	Time		Car Number	Time
1	94	10:44.35	28		
2	93	10:46.05	29		
3	95	10:47.25	30		
4	90	10:48.26	31		
5	84	10:49:25	32		

Value added/None value added form

This form is required to capture data at each station, Table 4.7. It is used to distinguish all value added time (VA) from none value added times (NVA) that occurs at each station . Each student assigned to a station is required to establish the VA and NVA by using the continuous timing method that requires the clock be started at the beginning of the simulation run and stopped at the end of the simulation. By using the lap feature of the stop watch the entire simulation run time can be demarcated into smaller intervals that represent VA and NVA times, figure 4.27.

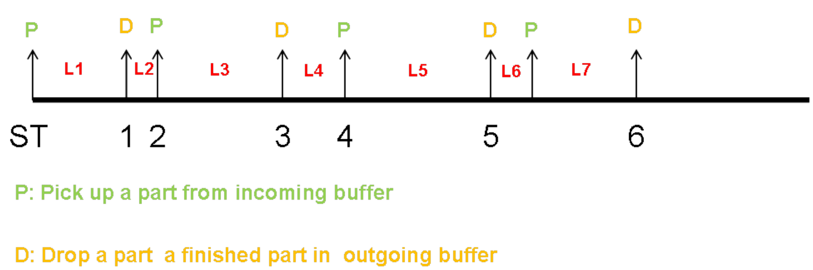


Figure 4.27: Establishing VA and NVA times at each station

Figure 4.27 illustrates how the VA and NVA times at each station are established using a stopwatch. The numbers in figure 4.27 represent events. At the start of the simulation run (Event ST) each operator begins timing by pressing the start button on the stopwatch, and the end of processing of a unit (Event 1) the operator will use the lap button. The lap button allows the interval between the start and end of processing to be stored in memory as Lap 1 (L1), in figure 4.27). When the operator picks up a new part for processing (Event 2), he/she will once again press the lap button to indicate the beginning of processing of a new part. The interval between event 1 and event 2 is stored as Lap 2 in the memory of the stop watch. This process of lapping at each successive start and end point of the processing cycle is continued for the entire duration of the simulation time. As a result, a series of lap times are stored in memory. It is evident from figure 4.27, that odd lap times represent VA and even lap times represent NVA. The lap times can be recalled from memory at the end of the simulation run and recorded into a VA/NVA analysis sheet shown in table 4.7

Table 4.7: Value added Non-value time analysis

Value added/Non value added analysis

Stop watch number:	14
Station:	1
Watch Operator:	Hannah Thummel

Laps	Time		Laps	Time	
1	1:19.39	VA	31	1:26.63	VA
2	2.36	ID	32	9.80	ID
3	1:22.75	VA	33	1:07.83	VA
4	2.90	ID	34	3.32	ID
5	1:20.79	VA	35	1:20.86	VA
6	4.82	ID	36	3.75	ID
7	1:16.51	VA	37	1:13.75	VA
8	4.80	ID	38	1.14	ID

Table 4.7 shows recorded values of VA/NVA added times that were retrieved from the stopwatch at the end of the simulation run. The values were then analyzed using a spreadsheet template provided to compute the average VA and average NVA times at each station (see appendix C, table C.1, and table C.2. The VA times represent the actual service time (processing time) while the NVA represent the idle time that resulted from blocking or starving at a station. A station was considered starved if processing at the station could not be done because work in process (WIP) from an upstream process was not available, and blocked if the station could not continue processing parts due to its output buffer being full.

4.5.3 Student's Assembly line Balancing labs

Students' line balancing lab consisted of a series of three labs, namely:

- **Production run-1**: Simulate the traditional production systems where WIP between stations is uncapped , and lot sizes are bigger. This simulation was designed so that students could identify inadequacies in the system, and earmark them for improvement in the subsequent production runs. Line balance metrics are calculated and compared to theoretical line balance metrics.

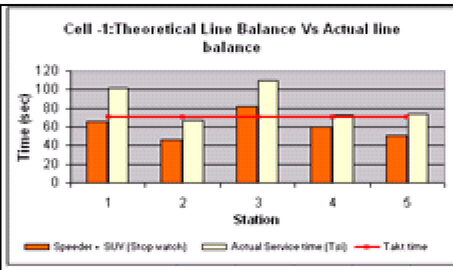
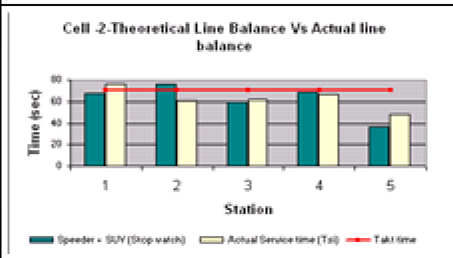
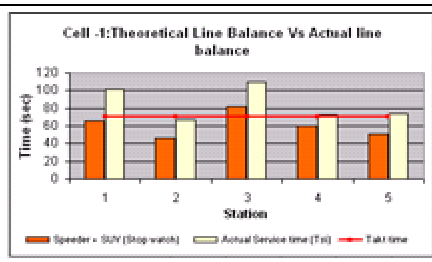
- **Production run-2**: Represents the first attempt of re-balancing the line using line balancing methods discussed earlier. A total of four lab groups (Monday and Tuesday) were involved in the simulated runs. Two groups were assigned to the manual line balancing lab using Excel decision support system discussed earlier, while the other 2 groups (Wednesday and Friday) used the computer based line balancing software Probalance . This production run is also intended to expose any flaws present in the line balance solution.

- **Production run-3**: Is the final simulation run using the same line balancing solution presented in production run two, but with refinements facilitated through continuous improvement meeting among team members.

Production run-1 results

In the first production run (Production run-1) student groups were given a target of 51units/hour. No additional instructions were given regarding how to run their cell. Without the students' knowledge, each cell was presented with an unbalanced line as shown in figure 4.26, pagerefUnbaLineBalaceCh. During this live simulation run, students were required to record data using two data collection forms provided (Throughput data form and Value added/None value added form)

4.5.4 Results of assembly line line balancing labs

		Production run 1					
		Actual			Theorectical		
		E_b	E_d	Throughput Units/hr	E_b	E_d	Throughput units/hr
Cell-1		78%	22%	38	74%	0.26	44
Cell-2		82%	18%	44	81%	0.19	47
Cell-3		76%	24%	38	70%	0.3	39

Speeder + SUV (Stop watch) Actual Service time (Tsi) Takt time

Figure 4.28: Production run 1 results

Figure4.28 shows the result of running the unbalanced line, which is representative of the traditional production system in which WIP is uncapped, and the lot sizes are much bigger. In figure 4.28, the yellow shaded bars represent actual service (T_c) time at a station during the production run, while the other bars represents the station cycle time established through stopwatch time study. It can be seen that the theoretical LB solution was close to the actual LB, indicating the stopwatch time study was a good predictor of the actual line balance solution. The theoretical throughput rate however appears to be slightly higher than the actual throughput rate. From Figure 4.28, it would appear that actual times (T_{si}) obtained during the production run in most were cases larger than the stopwatch data.

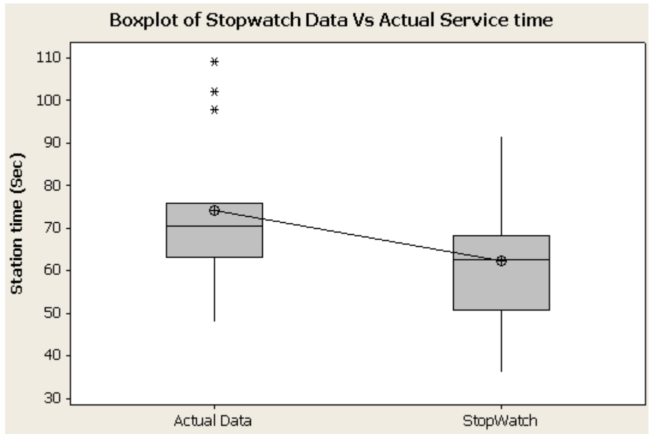


Figure 4.29: Boxplot of stopwatch service time Vs Actual service times

Paired T-Test and CI: Actual Data, StopWathc

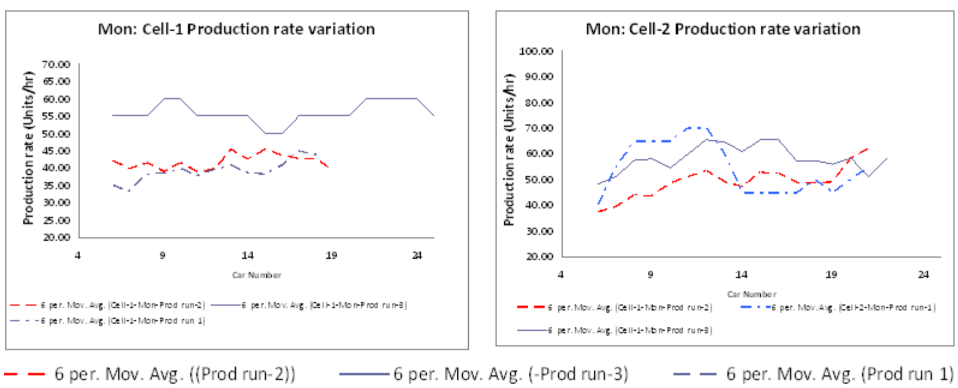
```
Paired T for Actual Data - StopWathc

              N     Mean    StDev  SE Mean
Actual Data  15  74.0369  16.6788   4.3065
StopWathc    15  62.2047  14.2384   3.6763
Difference   15  11.8323  12.9865   3.3531


95% CI for mean difference: (4.6406, 19.0240)
T-Test of mean difference = 0 (vs not = 0): T-Value = 3.53  P-Value = 0.003
```

Figure 4.30: Paired t test for comparing Stopwatch data to Actual service times

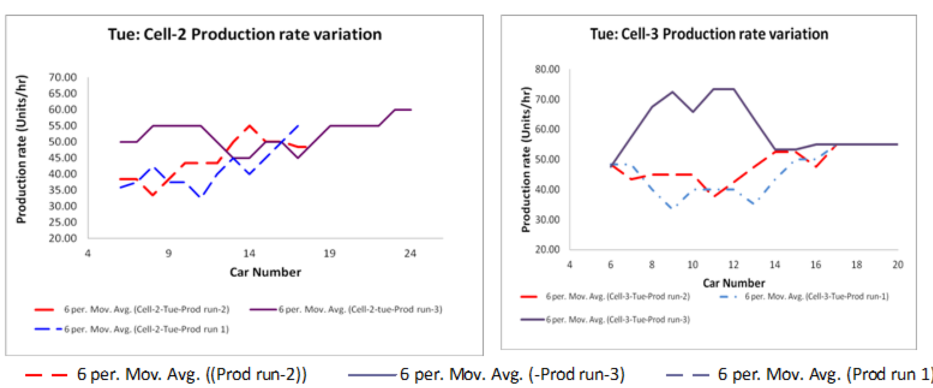
A paired t-test for comparing the stopwatch service times to the actual service times indicates that there is sufficient evidence to suggest that stopwatch time study did underestimate the actual service time at each station for production run-1.

4.5.5 Results of running a balanced line (Production run-2 and Production run-3

After the students had experienced the inadequacies of running a traditional assembly line characterized by unbalanced workstation service times (T_{si}) and uncapped buffers between stations and cells, new work instructions were created using line balancing solution generated from students line balancing lab. Two sets of line balancing solutions were generated and used for two groups of students. The first line balance solution generated used the manual assembly line balancing method with time study data as input, while the second line balance solution used Pro-balance computerized line balancing method with MOST predetermined time study data as input. Figure 4.31 shows the variation of throughput rate with time for three successive production runs.



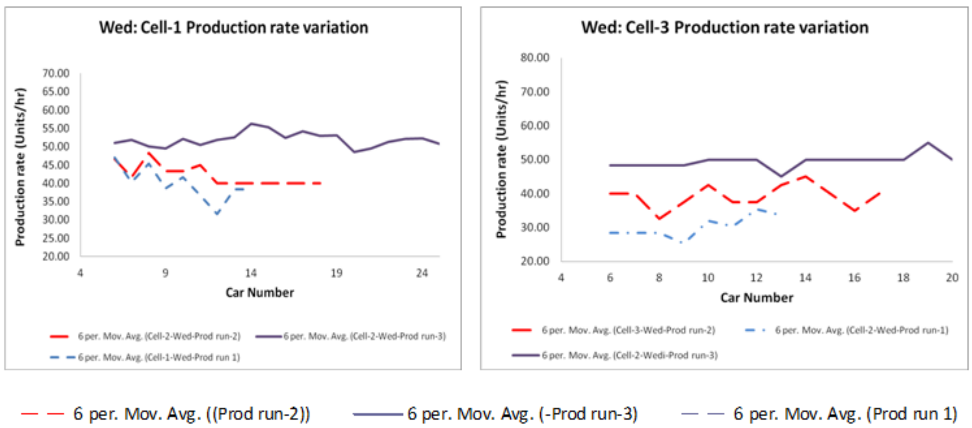
(a) Monday group production run comparisons



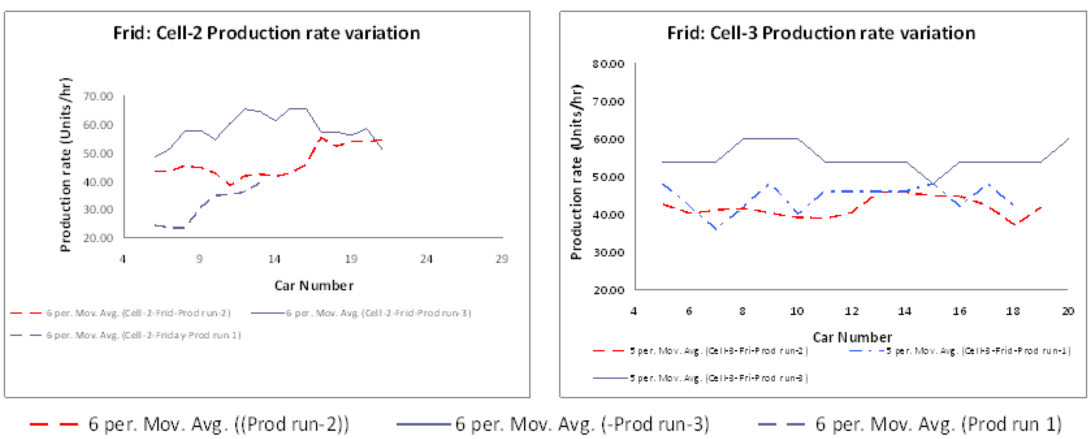
(b) Tuesday group production run comparisons

Figure 4.31: Manual line balancing method with stop watch data input

Figure 4.31(b) shows the results three productions. Production run-1 represents the unbalanced production runs, while productions runs 2 and 3 were done after the implementation a manual line balancing solution. Production runs 2 and 3 show a better throughput rate compared to production run-1. The results indicated that all production runs yielded significantly different throughput rates as indicated by One way ANOVA analysis.



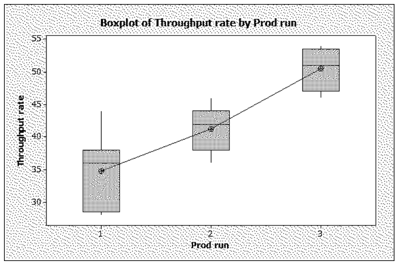
(a) Wednesday group production run comparisons



(b) Friday group production run comparisons

Figure 4.32: Probalance Computerized line balancing method with PMTS data input

Figure 4.33 shows the result of comparing the performance of three production runs for all groups that participated in live simulation runs. The results indicate significant improvements in performance from the unbalanced production run-1. With each successive production run, performance of the systems improved, with the final production run showing the best performance. Production run-2 resulted in an improvement of 17% from production run-1 and Production-3 resulted in a 21% increase in throughput rate from production run-2. Production run-3 shows an overall improvement of 47% from the prior unbalanced state.



(a) Box plots

One-way ANOVA: Throughput rate versus Prod run

```
Source    DF      SS     MS      F      P
Prod run   2  1002.3  501.2  27.06  0.000
Error     21   389.0   18.5
Total     23  1391.3

S = 4.304   R-Sq = 72.04%   R-Sq(adj) = 69.38%

                           Individual 95% CIs for Mean Based on
                           Pooled StDev
Level  N    Mean  StDev  -------+---------+---------+---------+--
1      8  34.750  5.651  (----*----)
2      8  41.250  3.694            (-----*----)
3      8  50.500  3.162                            (----*----)
                         -------+---------+---------+---------+--
                             36.0      42.0      48.0      54.0

Pooled StDev = 4.304
```

(b) One way Anova

Hsu's MCB (Multiple Comparisons with the Best)

```
Family error rate = 0.05
Critical value = 2.02

Intervals for level mean minus largest of other level means

Level    Lower   Center   Upper   +---------+---------+---------+---------
1      -20.101  -15.750   0.000   (---*---------------)
2      -13.601   -9.250   0.000         (----*--------)
3        0.000    9.250  13.601                     (--------*----)
                                  +---------+---------+---------+---------
                                -20       -10         0        10
```

(c) HSU compare

Tukey 95% Simultaneous Confidence Intervals

```
All Pairwise Comparisons among Levels of Prod run

Individual confidence level = 98.00%

Prod run = 1 subtracted from:

Prod
run    Lower  Center   Upper  -----+---------+---------+---------+----
2      1.083   6.500  11.917                  (-----*----)
3     10.333  15.750  21.167                           (-----*----)
                              -----+---------+---------+---------+----
                                 -10         0        10        20

Prod run = 2 subtracted from:
Prod
run   Lower  Center   Upper  -----+---------+---------+---------+----
3     3.833   9.250  14.667                    (----*-----)
                             -----+---------+---------+---------+----
                                -10         0        10        20
```

(d) Tukeys

Figure 4.33: Production runs throughput rate comparisons

Figure 4.33(a) shows the box plots of the means for the three production runs. The one way ANOVA analysis using simulation run number as the factor of interests and throughput rate as the dependent variable showed the mean throughput rate to be significantly different as indicated by an extremely small p-value. Hsu's MCB (Multiple Comparisons with the Best) compares each mean with the best (largest) of the other means. Figure **??** clearly indicates production run-3 to be the best.

4.5.6 Comparison of Computerized line balancing method with Manual assembly method

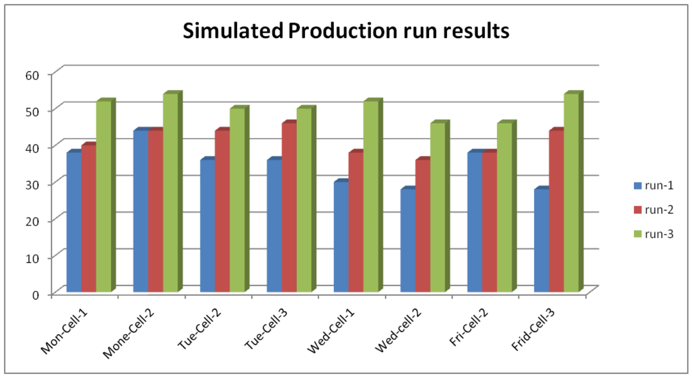


Figure 4.34: Simulation run production run results

Figure 4.34 shows the results of running three simulated production runs. The Monday and Tuesday simulation runs used the manual assembly method with stop watch time study input while the Wednesday and Friday groups utilized computerized line balancing method with PMTS standard time data as input. The two methods were compared to determine which method would lead to a better performance.

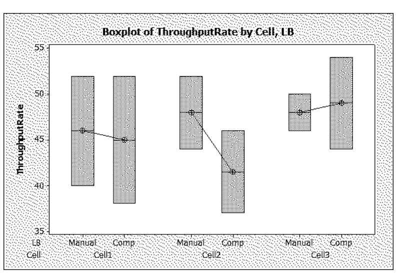


Figure 4.35: Throughput rate vs LB method by Cell

Main Effects Plot (fitted means) for Throughput rate

Results for: CompVSManual

Two-way ANOVA: ThroughputRate versus Cell, LB

```
Source       DF       SS       MS     F      P
Cell          2   31.500  15.7500  0.31  0.742
LB            1   14.083  14.0833  0.28  0.615
Interaction   2   30.167  15.0833  0.30  0.751
Error         6  300.500  50.0833
Total        11  376.250

S = 7.077   R-Sq = 20.13%   R-Sq(adj) = 0.00%

Individual 95% CIs For Mean Based on Pooled
            StDev
Cell   Mean   +---------+---------+---------+---------
1     45.50     (--------------*-------------)
2     44.75   (--------------*-------------)
3     48.50          (--------------*-------------)
              +---------+---------+---------+---------
            36.0      42.0      48.0      54.0
```

Figure 4.36: LB vs Cell 2way Anova

Figure ?? shows that for Cell-1 and Cell-2 the manual LB method with stopwatch input data had better performance than the computerized LB method with PMTS data . However, cell 3 indicated a better performance for the computer LB solution compared to the manual LB method. Figure 4.36 shows the two way Anova analysis with Line balancing method as one factor at two levels (Computerized LB and Manual LB) and manufacturing cell as the other factor at three levels (Cell-1, Cell-2, and Cell-3. The throughput rate of each cell was used as the the response variable of interest. The p-value (p=0.615) for the LB method suggested that LB method, time standard combination had no significant impact on the output of the system. However, it should be pointed out that the manual LB method showed better output.

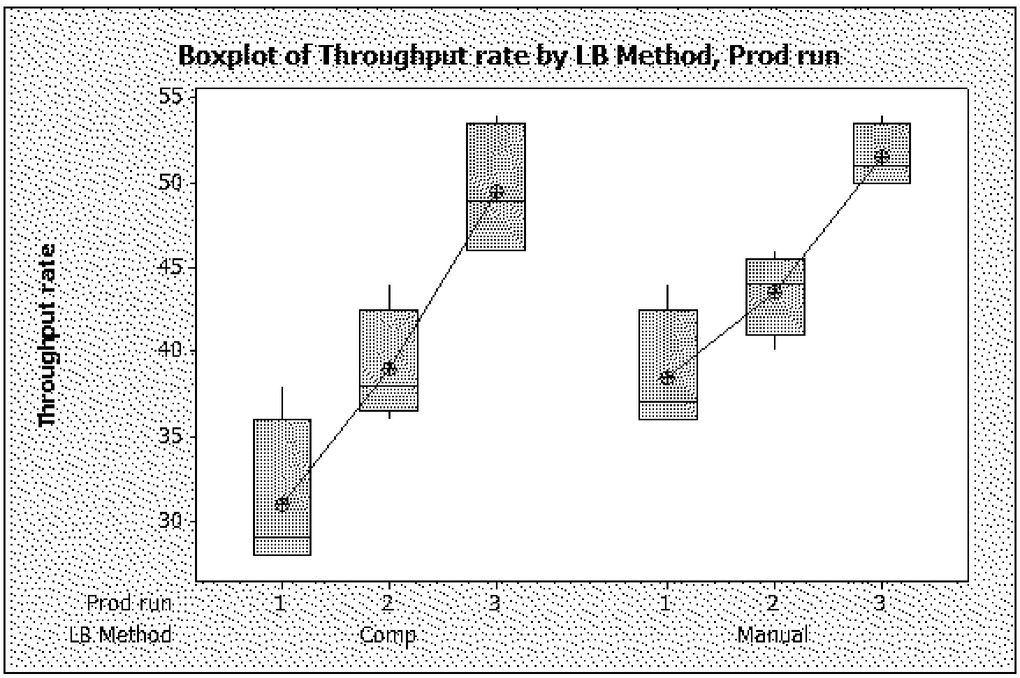


Figure 4.37: Boxplot of Throughput rate by LB Method, Prod run

4.5.7 Discussion

The purpose of engaging students in a hands-on learning experience was to provide students with a realistic learning experience that was as close as possible to real life work related problems. Tiger Motors simulated factory provided such an environment as students were engaged in a number of interrelated tasks, all of which were designed to accomplish a single objective, to build an efficient manufacturing system able to meet the throughput requirements thus set. In order for the goal to be accomplished students had to put theories taught in class into practice. For instance students were required to learn how to establish time standards through stopwatch time study. The same time standards established by students were then used as input in a line balancing problem. Since students' overall performance was directly linked to the performance of their manufacturing cell with respect to throughput rate and the quality of product manufactured, it became apparent to students that those goals were dependent on how well individual hands-on activities such as, time study, line balancing, standardized work documentation, and group continuous improvement activities were done. Because of these interrelated tasks, all of which impacted the overall goal, students were motivated to take each individual lab seriously. The line balancing lab was especially challenging for students since it required students' involvement in all aspects related to the line balancing problem. Typical line balancing problems assigned to students are in book problems that provide the precedence constraints to students. However, the lab line balancing problem was unique in the sense that students where provided with a physical model of the product as well as the assembly drawing from which they were required to establish precedence of operations, culminating with the establishment of a precedence diagram. This was a vital step which the students found challenging, but afforded students the unique opportunity of developing a particularly important skill-set associated with realistic line balancing problems. The opportunity for students to interact with the physical model was also important in emphasizing design of assembly principles, an important principle that is difficult to demonstrate in a classroom setting.

Students were able to solve the line balancing problem using manual heuristic procedures discussed in class. Once a group consensus regarding a line balancing solution was reached, there was need to create new work instructions to reflect changes in the assignment of operations to stations. Students experienced the importance of creating proper standardized work documentation. This became apparent when quality problems arose attributed to poorly designed standardized work documentation. It became apparent how the integration of human factors design concepts may be a future hands-on learning activity needed to be integrated into the lab, thus adding to the interdisciplinary learning activities the lab provides.

The results of the live simulation runs indicated improvement in system performance with each successive simulation run, indicating that each hands-on activity prior to the simulation contributed to performance improvement. Students were able to see first hand these improvements which likely increased their confidence and belief in their ability to use the tools taught in class and put into practice in the lab.

While the purpose of the hands-on learning activities associated with line balancing lab offered in the INSY3800 course was mainly to provide realistic problem solving experience to students, it also provided opportunities for answering pertinent research questions relevant in the practice of industrial engineering and manufacturing. Establishing accurate time standards are a vital component in the efficient design of many manufacturing system. The lab provided us with the opportunity to compare two methods for establishing time standards and assess the potential effect on establishing a good line balancing solution. Stopwatch time study, which is a direct method, was compared with MOST, which is an indirect method. Stopwatch time standards were established by timing a competent worker working at a perceived normal speed. One limitation to this study was that although the time study

study standards established using a competent worker, the competency of each worker at the given station was not verified. Another limitation to the study of the hands-on labs setup was the inadequacy in exposing the presence of interaction effects between the line balancing method used (Computerized LB and Manual LB) and the method used to establish time standards (Stopwatch time study and PMTS). Because of variation that exists assembly task times within the worker used in establishing standard times it was hypothesized that the use of PMTS time standard would yield a better line balance solution. The results indicated that no significant difference between the two methods used for establishing time standards, thus implying that despite the method used, the actual line balance metrics are not significantly different. However, the performance of line balancing using stopwatch time standards appeared to have relatively better performance with respect to the throughput measurement. An additional limitation is that we assume the performance of each group is not hindered by incompetent group members whose task times may significantly differ from the expected task times.

4.5.8 Conclusion

In this past section we investigated the effect of the method used for established time standards on quality of the line balancing solutions. Because of the variability in the task times between different operators, as well the within operator variability, it had been it had been ascertained that using predetermined time standards as input to a line balancing solution would yield a better quality of a line balancing solution. Results indicated that predetermined time study underestimated the the actual time spent on an assembly task. Despite the difference in task times between the two methods, the quality of the line balancing solution seemed unaffected by the method used to establish the times standards. However, the solution derived from stopwatch time study yielded a better solution. In conclusion, we can confirm that predetermined time studies could be used interchangeably as input to line balancing solution. However, it should be indicated that one has to cognizant of the fact that material handling issues, particularly for very small and difficult to handle parts could lead inaccurate standard times when using predetermined time methods.

4.6 A hands-on Robotics lab for teaching introductory automation

Students taking the INSY3800 course were introduced to a hands-on automation class. Automation is included as part of the classroom lecture material where students are introduced to the concepts regarding automation, such as the different roles that robots play industry. Students were presented with videos of different types of hands-on labs designed to reinforce the classroom material. In the classroom students typically participate as passive learners, however the introduction of the hands on lab component allows students to become active learners. While engaging students in hands-on laboratory work, where they are encouraged to interact physically with the hardware is , it is not always possible due to number of limitations, such as:

- Lack of adequate hardware needed to perform the lab
- Lack of adequate staffing for setting up the lab and maintaining the equipment required
- Safety associated with students interaction with equipment or machinery

Virtual learning environments have been one way used for overcoming constraints listed . In virtual environments, students do not interact with the real equipment to obtain data, learn concepts, or develop skills, but rather make use of computer simulations of the laboratory with industrial equipment. In the most common approach, the virtual laboratory is used as an alternative mode and simulates a similar set of activities in the corresponding physical laboratory (Korecky, 2011) . While virtual laboratories may sometimes be used as a replacement for physical laboratories , it is generally agreed that such laboratories are more effectively used in conjunction with physical laboratories.

Considering the constraints described which were relevant to our situation, a hybrid system consisting of a computer simulated lab module and physical equipment was developed for the purposes of affording students the opportunity to actively participate in an introductory automation class. A robotics lab module was introduced as part of INSY3800 labs with the objective of giving students a general overview of application of industrial robotics in a manufacturing industry. In this lab students were introduced to basic robot architecture to included the different robot geometries and their suitability to particular applications in industry. A discussion was held in the lab to describe the various types of robots that are found in manufacturing industry. To illustrate an industrial robotic application, a semi-automated assembly operation was selected and developed for demonstration purposes. A semi-automated assembly station was proposed for integration into the Tiger Automotive Assembly Plant. The semi-automated station allowed the Lab TA's to give students a practical demonstration of an industrial application of robotic assembly. After preliminary discussion about industrial application of robots, the TA demonstrated to a small group (about 10 students) the various components of a robotic system and how the interaction among the various elements takes place. Because of the large number of students, safety was the primary concern considering that many of the students had no experience with large industrial equipment. However students were actively able to participate by developing a robot program required for automated assembly of Lego blocks on a base secured on a fixture.

Figure 4.38 shows the layout of the semi-automated robotic assembly station. Lego parts are automatically assembled at this station . The station is integrated with into model manufacturing system that includes mostly manual assembly stations. The integration of automated semi-automated stations affords students to learn about the basics of automation. The integration of the semi-automated station is accomplished in the following manner:

Conveyor robot interfacing:

1. At position 1, material handler feeds a pallet containing parts that are required for automated assembly.

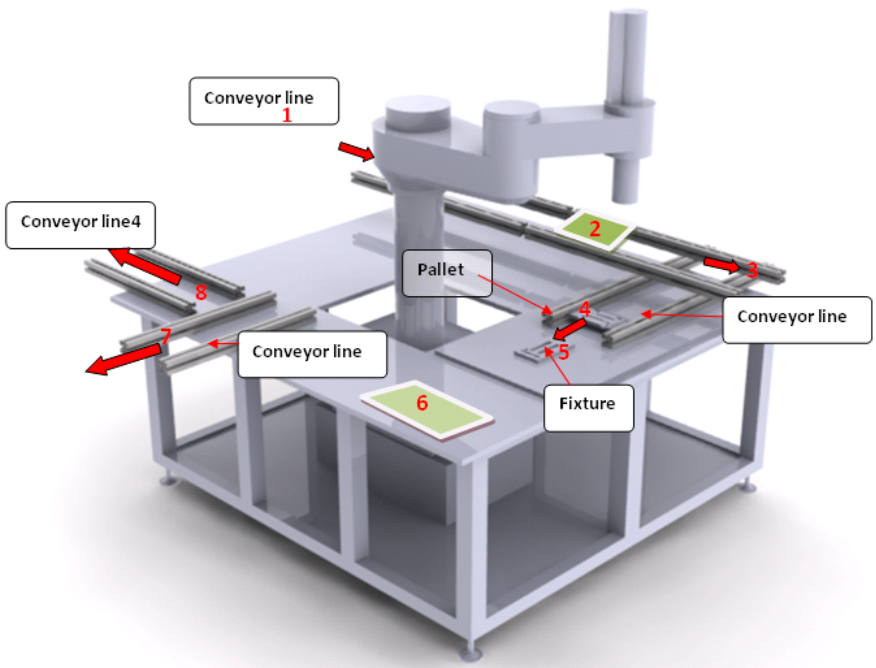


Figure 4.38: Semi-Automated robotic assembly station

2. When pallet of raw material parts reaches position 2, conveyor stops and a signal is sent to the robot to indicate that the pallet in position. Each pallet may contain as many as 12 individual parts that are to be assembled onto the sub assembly.

3. The sub assembly is a manually fed by an operator at station 1 onto the robotic assembly station using conveyor line # 2.

4. On reaching position 4, pallet carrying sub Assembly stops.

5. The presence of both in-process parts at position 2 and sub assembly at position 4, as indicated by steps 2 and 4, activate the robot to begin the assembly process.

6. Robot picks up pallet (sub assembly) and places it in the fixture.

7. Robot picks up individual parts in position 2 and attaches them to the subassembly positioned at 5 as required.

8. When robot picks up the last part from the raw material pallet, the conveyor is set in motion again and the empty pallet exits at the end of conveyor to be re-circulated back to the in feed position.

9. After the last piece is assembled, the robot picks the pallet and positions it at position

six where automated vision inspection is carried out.

10. If a part is found to be free of defects, it is placed on conveyor line # 7 which is automatically activated by presence of pallet, otherwise it is placed on conveyor line #8, which conveys defective sub-assemblies for rework.

Designing and fabrication of tooling and fixtures for Robot

In any automated assembly tasks there is always a need to develop tooling and fixtures needed to assist in the assembly task. This need provides a further learning opportunity for students to actively participate in the design and fabrication of tooling and fixtures required. In the case of the automated assembly station, there was a need to develop a custom gripper that could handle two different dimensions of Lego blocks. Designing of the gripper and holding fixture was done using auto-cad and the parts were fabricated using 3D printing.

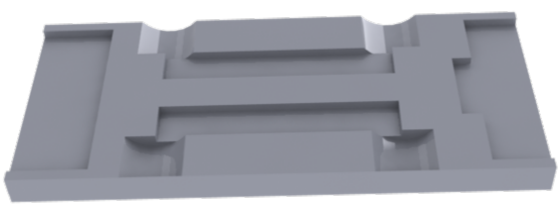


Figure 4.39: Cell Production run 1

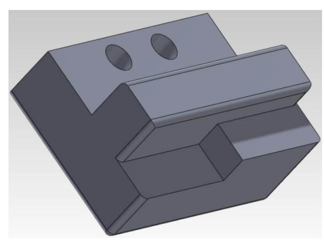


Figure 4.40: Cell 2 Production run 2

4.7 A hands on programmable logic controller lab

Programmable logic controllers (PLCs) are the cornerstone of automation in many industrial factory floors and are likely to remain predominant for some time to come. Most of this is because of the advantages they offer. The use of PLCs offer a number of advantages that include: 1)Cost effectiveness in the control of complex systems, 2) Flexibility and ability to be reapplied to control other systems quickly and easily, 3)Computation abilities that allow for sophisticated control, 4)trouble shooting that make programming easier and reduce downtime, and 5) Reliable components, making them likely to operate for years before failure.

Basic understanding of PLCs is normally required in many industrial and manufacturing engineering curricula. However, many curricula do not offers hands-on learning activities. In order to afford the hands-on learning experience in basic automation and PLC concepts, a PLC trainer was built. The PLC trainer was built using aluminum profile with a basic Siemens PLC and a human machine interface (HMI) attached to it. This configuration is shown in figure 4.41:

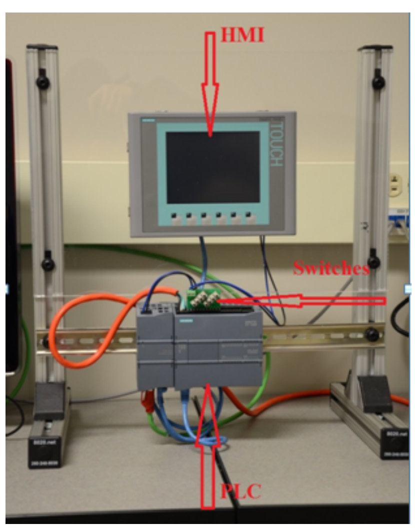


Figure 4.41: PLC training station

The basic components of PLC include ; Processor, Memory unit, power supply, input/output modules and a programmable device. The processor and memory unit reside in the CPU as indicated in figure 4.41, while an external power supply is secured next to it. The inputs to a PLC can be provided by a number of different automation sensors such as limit switches, photoelectric electric switch, proximity switch etc. Output signals from the PLC are used to control output devices such as a signal light, and actuators such as motor starters and solenoid valves. The PLC training station shown in figure 4.41 has the ability to use both physical inputs from sensors as well as virtual inputs provided in PLC programming software (Siemens TIA portal software). The HMI screen shown in figure 4.41 had the ability to simulate a variety of sensor inputs and output normally found on the factory floor.

PLC are able to control complex systems by making use of programming language called ladder logic. Students understanding of the basic interaction between sensor inputs, ladder logic programming for controlling output signals based on the inputs, was the major learning objective of the hands-on PLC programming lab. By making use of timers, counters, and other mathematical calculations, students were required to establish an industrial control system of their choice.

4.7.1 Students PLCs lab projects

The PLC lab consisted of three lab session with each lab session lasting three hours. In the first lab session an introduction of PLC was given to students and video of typical PLC use in an industrial factory floor setting was shown. A demonstration was then given to show the actual components of a PLCs as described in section 4.7 with lot of emphasis placed on the input states and output state signals. A demonstration on how to create a simple ladder logic using the TIA portal software was given, after which students were assigned a simple assignment which required them to create simple PLC program using the following steps:

1. Compiling
2. Debugging
3. Downloading to PLC and HMI

The purpose of first lab was to give familiarity to students on the concepts and operations of PLC. At the end of the first lab, an assignment was given which would be due on at the beginning of next lab. The second lecture consisted of more complex PLC control utilizing counters, function blocks, as well as using HMI to animate input sensors and various outputs. An open ended project was then assigned to students at the end of the PLC Lab. The project required that students create a PLC application of an industrial application that demonstrated the use of timers, counter, and any combination of sensor input and outputs.

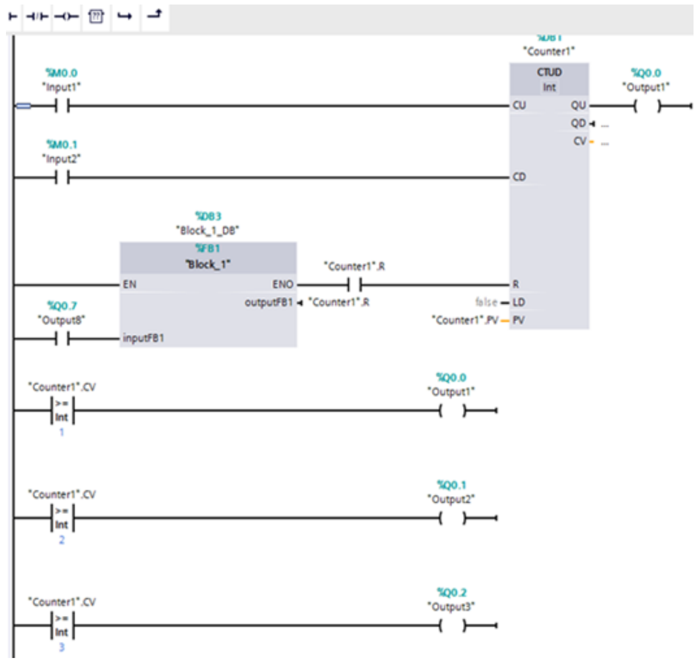


Figure 4.42: PLC ladder logic for Machine batching project

Figure 4.42 shows the ladder logic developed by one group for their project. The objective of the project was to use a PLC to control drilling machines, which became activated when ever the number of parts on the conveyor reached a preset value. They used lights on the HMI to represent whether the positions are occupied by parts.

4.8 Student perceptions on introductory manufacturing lab in enhancing student learning and interest

The effectiveness of students' hands-on learning can not be complete without careful assessment of student outcomes. Many different assessment methods are available for evaluating the effectiveness of hands-on learning labs. These methods include evaluations of student performance on tests, as well as using surveys to gather student feedback regarding their understanding of the subject. As part of evaluating the effectiveness of the newly developed hands on learning activities described in earlier sections of this research, a survey was created to gather students' feedback on how participating in labs impacted their understanding of the course material (see appendix E). Students' opinions regarding their participation in the lab was the primary source of data. A total of 80 students who took an INSY 3800 course in the spring of 2013 participated in the survey. Participants of the survey were composed of 1.25% juniors, 1.25% sophomore, 66% Junior, and 31% Seniors. 47% of the participants in the survey indicated interest in a career in manufacturing. One of the ABET engineering criterion requires that engineering faculty should involve students in explicit instruction in a workshop or cooperative learning format. 46% of the students taking the class had no prior internship experience, thus further emphasizing the need for learning that affords realistic practical experiences. Prompting the employability skills of students is one of the goals of the developing hands-on learning labs. Since students, along with employers, and faculty are considered stakeholders of engineering education, their opinion regarding employability skills are equally important. Students were asked a series of questions regarding their experiences in the lab. In 80% of the of questions, students were asked about their level of agreement regarding a statement, while 10% of the questions were open ended questions where students could express their views in response to a question. A five point Likert scale, with scale points ranging from "Not at important" to "Extremely important", "strongly agree" to "strongly disagree", were on multi-choice and matrix type questions.

4.8.1 Students responses to survey questions

Students were presented with a number of statements in which they were required to respond using a five point likert scale where 1 is "Not at all important" and 5 is "Extremely important."

Statement 1. Given the identified competencies relevant to manufacturing, how important do you consider these competencies in preparing you for your future career. The identified competencies were listed as 1. Use of computer aided software CAD/CAM, 2. Knowledge of ergonomics and safety, 3. Lean manufacturing knowledge, 4. Operations research and Optimization . 5 MRP/inventory control, 6. Knowledge of manufacturing processes, 7. Statistical process control, 8. Automation knowledge , 9. Six Sigma knowledge, 10. Business knowledge and skills.

Figure 4.43: Desired employability skills of students

Figure 4.43 is a summary of student response to statement 1. Knowledge of business was ranked the highest among all other competencies. Lean manufacturing and operations research were also indicated as important competencies for students. Interestingly, students ranked the use of Computer aided design/computer aided manufacturing, as well as knowledge of automation, the lowest among the competencies deemed important.

Statement 2. Students were asked for their opinion on how they viewed hands-on labs in comparison to lecture only instruction in enhancing their learning ability. Student were asked to state their agreement/disagreement with the following statements:

1. I pay more attention when participating in labs than in lectures.

2. I tend to learn more in labs than lectures.

3. I learn better when I am part of a team.

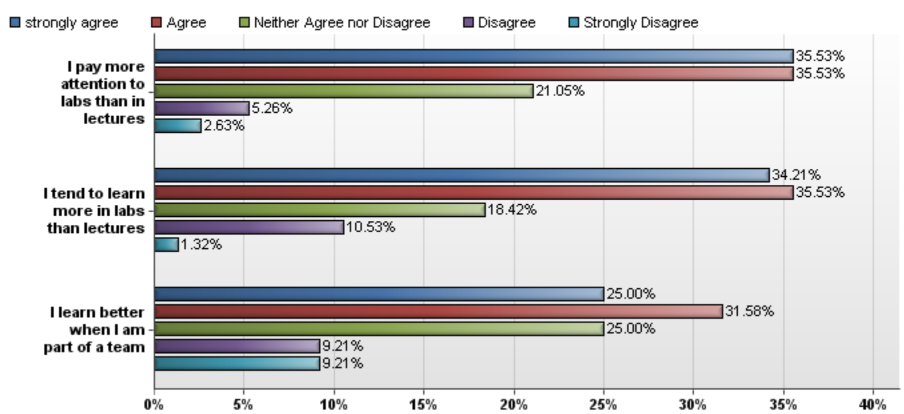


Figure 4.44: Students perception of their learning ability during lectures and in hands-on lab

Figure 4.44 shows students' responses to statement 2. Students' responses indicated that more than 60% of students strongly agreed with statements 1 and 2, and around 55% agreed that working as part of a team benefited their learning ability. However, around 20% of the students were more in favor of individual work than working in teams.

Statement 3. Because students were grouped differently in each lab, both in terms of the number of students in a group, as well as personnel makeup, it was important to determine students opinion regarding what they thought was optimum group size. Depending on the lab activity and availability of equipment, group size ranged from two people in a group to ten people in a group. Based their lab experience, students were asked to select a group size they deemed effective for team work. Student responses indicated that 70% of students favored group sizes of between two and four people in a group, with 25% of students in favor of no more than two people in a group.

Statement4. Since the lab seeks to equip students with conceptual understanding of manufacturing concepts, as well as facilitating life long career skills, it therefore became important that labs should be designed around skills students are likely to use in industry yet are not readily practiced in an academic setting. Students were asked to indicate if they had any prior practical experience with any of elements taught in the lab. The lab elements included: 1. Stopwatch time study/Predetermined Motion and time studies, 2. Robotic programming/Automation with Programmable logic controllers, 3. Assembly line balancing , and 4. Computer Numerical Control (CNC)

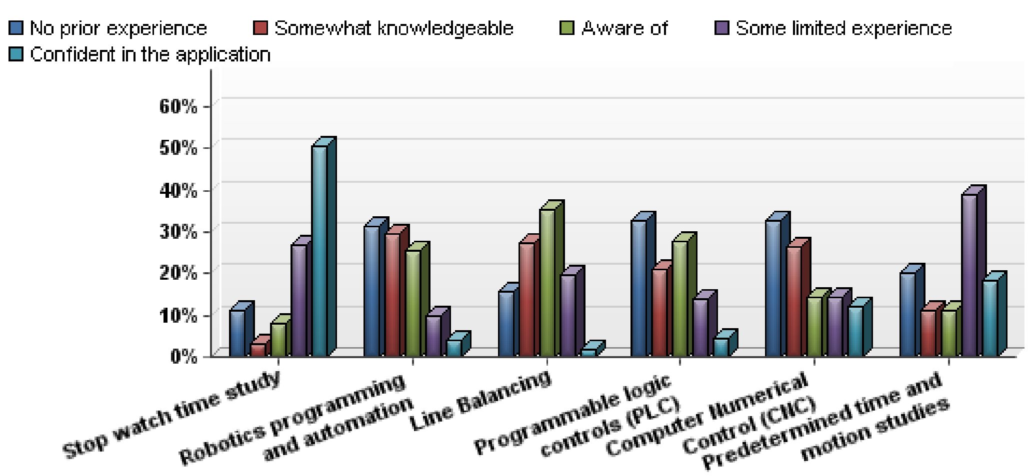


Figure 4.45: Students prior practical experience with lab elements

Figure 4.46 indicates responses to statement 4. The most prior practical experience students had with any of the lab elements taught were Stopwatch time study and Predetermined motion time studies. About 50% of the respondents indicated having prior practical experience with stop watch time study. However, with other lab elements students appeared to lack any practical experience. For instance, around 70% of students indicated as having between no practical experience to some awareness with regards to practical assembly line balancing. In addition, 43% of the respondents had never participated in an internship, thus lacked the necessary practical experience.

Statement5. This question was designed to gage how realistic and practical the lab elements were to students. Since the labs included a combination of physical simulation environment (Lego lab), as well as virtual learning environments in the form of computer simulators (Robotic Programming and CNC programming), students were asked to indicate their agreement regarding how realistic and practical each of the lab elements were.

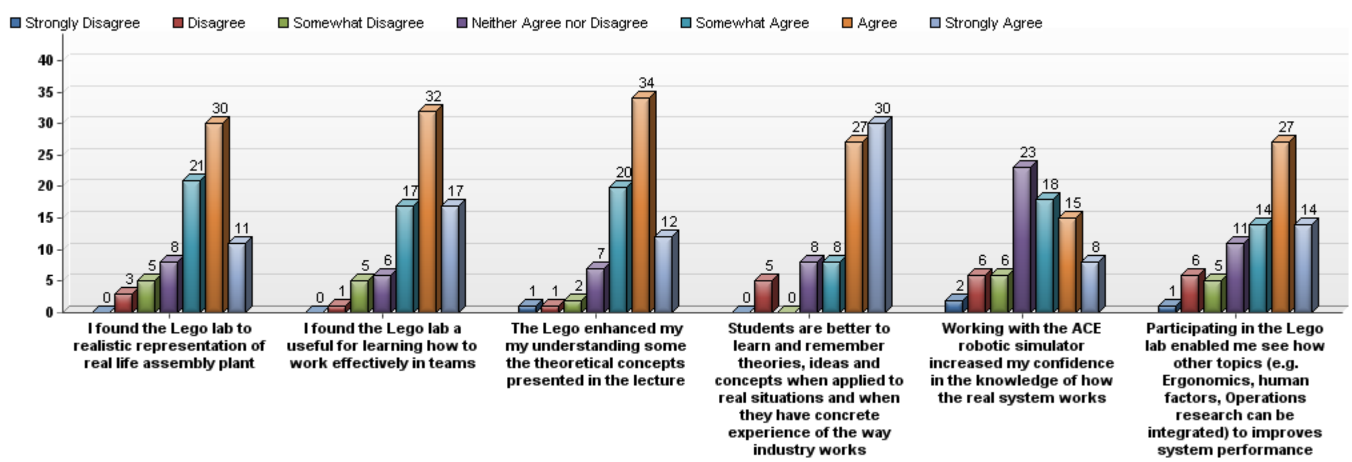


Figure 4.46: Students prior practical experience with lab elements

Statement6. This question was designed to gage students' perceptions on the effectiveness of the use of virtual learning environments in enhancing students' conceptual understanding and skills development. Students participated in labs where they had to develop a CNC code in a virtual learning environment. CNC programming is used in many manufacturing processes, particularly in metal cutting operations.

Students were also introduced to basic automation principles through their participation in lab where they were required to use a combination of physical automation hardware and a virtual PLC simulator. The setup allowed students to experiment with automation concepts used for controlling industrial machines and equipment normally found in many industrial settings. In addition, students were also engaged in a hands-on robotic programming in a virtual learning environment.

Figure shows students' responses to how they viewed the use of virtual learning environments. Overall students showed a positive attitude on the use of virtual learning environments, with about 70% of students indicating that using the virtual learning environments enhanced their understanding of concepts.

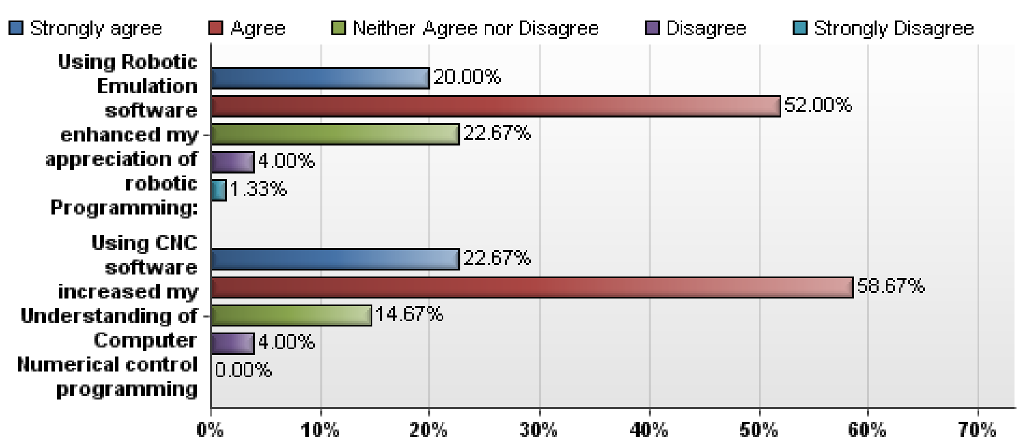


Figure 4.47: Students perception on virtual learning environments

4.8.2 Conclusion

Students' perceptions on the value of hands-on learning supports the notion, that hands-on learning introduced in manufacturing curriculum not only motivates to students, but could be useful in developing particular skill sets valuable to employers. Hands-on labs develop students interdisciplinary skills as students of various backgrounds interact together with the sole purpose of solving the problem at hand. A combination of both physical simulations and virtual learning environments can be used to successfully reinforce classroom lecture. From the survey it was apparent that students appear more focused towards subject matter during hands-on learning activities than during lecture.

Chapter 5

A hands-on approach to enhancing student learning in Lean Production course

5.1 abstract

A major challenge in lean systems as a continuous improvement tool is identifying the best strategy for implementation. Lean implementation is a long term process that carries high risks in fast changing industries. The success of many Japanese firms can be attributed to their strong lean culture, which is team driven and emphasizes both hard and soft skills. Despite many American companies attempts at lean transformation, outcomes of these endeavors have not always been positive. It is our belief that in order for American companies to regain their competitive edge, there is a need to provide hands-on training in lean manufacturing at the grassroots level (Academic level). In this project we discuss how hands-on lean training has been incorporated as part of the learning initiatives associated with courses in Lean manufacturing at Auburn University. Despite the emphasis on the importance of hands-on experience in manufacturing education, the issue regarding the effectiveness of hands-on education has remained contentious among many. Four hands-on learning laboratories have been designed to reinforce student learning of lean manufacturing concepts. The results of these live lean simulations led to the development of a computer simulation model, which will be used as an additional learning tool in both lean manufacturing and manufacturing systems education. The computer simulation will provide students with an alternative method for analyzing many different experimental scenarios needed to understand how the system works. An assessment of the effectiveness of the labs in enhancing students learning is also described.

5.2 Introduction

Simply stated, Lean manufacturing is a system for total elimination of waste from an operation or process. It is a management philosophy evolved and adapted from the Toyota production system. The Toyota lean manufacturing philosophy of success can be attributed to a multifaceted number of factors that include strong cultural factors that emphasize teamwork and commitment to quality throughout the ranks. However, because these underlying Japanese cultural traits differ from western values that emphasize individual achievement, independence, and short term goals, there is a need to emphasize to the American companies the importance of integrating the hard skills with the soft skills. The hard skills are the generally accepted manufacturing/Industrial engineering tools (e.g. line balancing, value stream mapping, etc), while the softer skills are those that entail fostering behaviors, roles that are essential for a culture of continuous improvement (Badurdeen et al., 2009). lean manufacturing training requires learning of both soft and hard skills necessary for successful problem solving. By embracing the Toyota approach to learning, that allows people to learn from their mistakes, the manufacturing system lab hopes to foster the same cultural values that have allowed Toyota Motor Corporation to be successful. Toyota is viewed as a learning environment whose greatest resources are its people. A manager's job at Toyota is viewed as that of a facilitator whose responsibility is to coach workers to know how to solve problems. It is on this basis that the Lean manufacturing lab is operated. The TA's assigned for this class acted as managers while students played the role of empowered workers whose main responsibilities included finding solutions to problems in the system.

5.3 Background information in lean manufacturing training

The goal of many lean manufacturing is to reduce cycle time and increase the ratio of value added to the total cycle time (Shannon, 1997). Lean manufacturing training has over the years become popular in industry. However, over the years a number of educational institutions have begun attempts to integrate lean manufacturing course modules on lean management philosophy with varied degrees of success. Most lean manufacturing teaching in educational institutions has been focused on classroom teaching with limited guidelines available on how to conduct hands-on lean manufacturing training to reinforce classroom learning. Based on a review on lean manufacturing training by Budaurdeen et al.,2009, there is a dearth of published information on simulation and games from some of the better universities and colleges that offer lean manufacturing. Furthermore, despite a huge Internet presence of companies and institutions that purport to offer lean manufacturing training, there is little information on the design and implementation of the simulation games. In addition to the use of live simulations in the training of lean manufacturing, there has been an increase in the use of computer assisted simulation (Feinsten, Mann, & Corsun, 2002). However, despite some noted benefits of computer assisted simulation games (Wang, 2005), the effectiveness of computer simulations as a substituted for live simulations still remains arguable. The limitations of computer simulations as alternative to live simulations in lean manufacturing training has been attributed to its inability to facilitate realistic interactivity and collaboration between team members (Rolfe & Hampson, 2003, Wang, 2005)

Most of the simulations reviewed by Budaurdeen et al.,2009, focused on the use of lean tools in transforming a traditional push system into a pull production. The majority of these simulations involved short iterations usually done within constraints of time allowed for a classroom lecture, with few of the simulations being more intense and lasting much longer. The short iterations usually carried during a single lecture have been noted as limitation since students are not allowed enough time to reflect on the learning points and applications of lean principles. It has been noted that the failure of some simulation training to achieve desired learning outcomes may be attributed to the confusion in the roles of teacher/instructor and student interactions. While it is expected that an instructor/teacher should play the role of teacher/coach or facilitator, there have been many observed cases in which the instructor ended up playing the role of team leader. The role of the facilitator is not teach solutions to the problem but rather to guide participants on how to achieve the desired learning outcomes using the appropriate lean manufacturing tools.

A lack of realism is another noted problem found with many of the live simulation games available. It has been estimated that less than 5% of simulation games offered presented realistic environments while less than half were tactile. Most live simulation games were found to lack enough complexity and sophistication normally found in real environments. It has been noted that despite the failures experienced by a large number of companies in their lean manufacturing attempts, many of the simulation games offered as training for students fail to acknowledge that failure is part of lean transformation, as most of the simulations are designed in such a way as to represent success.

A good review of simulation games used for training in both industry and academy can be found in (Bardudeen et al.,2009 and Verma, 2003). In surveys conducted to determine the use of simulation in lean manufacturing, it was found that a majority of simulation games used in industry were developed by National Institute of Standards (NIST), while many others are adaptations of the NIST simulation games. Most of the simulation training programs offered cover a variety of simulation principles like 5S, setup reduction, value stream mapping, pull vs push production, and continuous improvement among many others. Most of simulation games are conducted over a number of iterations that can range from a little as an hour to a full day.

5.4 Methodolgy

This study required the participation of students enrolled in the lean production course (INSY 6800) at Auburn University. This is a dual level course composed of both undergraduate and graduate students. Typical enrollment for the course is around sixty students, with a third of the students being graduate students. The INSY 6800 course was designed to be a lecture only course. However, the instructor for the course required that students acquire some hands-on lean manufacturing experience by engaging in laboratory activities. Because (INSY 6800) did not have a lab component,and since the lab is limited to a maximum of 30 students, it was difficult to accommodate all sixty students in one lab session. This problem was overcome by equally dividing the class into two larger groups, A and B. All students in a particular group attended lab at the same time. Each Lab group was further subdivided into three smaller groups (Grp 1, Grp2,and Grp 3) of no more than 10 members. It is important to note that students were randomly assigned to the groups and each group consisted of at least 3 graduates students. Each group was requested to nominate a team leader, whose responsibilities included coordinating all lab activities. On designated days either group A or B would be required to attend a lab session to participate in a designated activity, while the other group attended the lecture. Whatever group was designated for a lab activity could still participate in the lecture by watching a recording of the lecture. The event calender for the activities associated with INSY 6800 are shown in 5.1:

			A			B		
Event number	Event type	Topic	Grp 1	Grp2	Grp 3	Grp 1	Grp2	Grp 3
1	Lab	Production Run-1	Yes	Yes	Yes	Yes	Yes	Yes
2	Lecture	Takt time, Pull vs Push Systems,	Yes	Yes	Yes	Yes	Yes	Yes
3		Value stream mapping, Mixed model lines						
4	Lab	Value stream Mapping	No	No	Yes	No	No	Yes
5	Lecture	Inclass quiz covering the events (1, 2, 3, 4)						
6	Lecture	Single Minute exchange of Dies	Yes	Yes	Yes	Yes	Yes	Yes
7		Standardization workstation/PFMEA	Yes	Yes	Yes	Yes	Yes	Yes
8	Lab	Single Minute exchange of Dies	Yes	No	No	Yes	No	No
9	Lecture	Inclass quiz covering the covering events (6,7, 8, 9)						
10	Lecture	Cellular Manufacturing Design strategies	Yes	Yes	Yes	Yes	Yes	Yes
11	Lab	Cellular Manufacturing Design strategies	No	Yes	No	No	Yes	No
12	Lecture	Standardization workstation/facility	Yes	Yes	Yes	Yes	Yes	Yes
13	Lecture	Inclass quiz covering the covering events (10. 11. 12)						

Figure 5.1: INSY 6800 calender of events and experimental design

For students to grasp the intricacies of a manufacturing system they need to understand the relationship between the various processes that make up the system. To start with, students were exposed to a traditional manufacturing system that is based on a push MRP schedule. This system was designed with the following characteristics:

- Long and inefficient change over process
- Large batch sizes between changeovers from one model to the other
- Large amount of buffer stock between Cell-1 and Cell-1
- No Limitations on the amount of WIP between stations
- No standardization on container quantities and transfer batches
- Individual misaligned MRP schedules at each Manufacturing Cell
- Unbalanced workload among stations

Individual groups were assigned to a particular manufacturing cell. The graduate students in the group were assigned team leader roles, with one graduate students selected by team members to be the overall team leader. With the teaching assistant playing the facilitator role, each group was required to schedule time outside of class in which team members were oriented to the assembly tasks required at each station. Orientation of team members included the following activities:

- Job training at each workstation
- Conducting a stopwatch time study to determine the standard operation time for each defined operation. Only the undergraduate members of the group were required to do this. Graduate students used predetermined time method (MOST) to establish the standard times for each operation.

The first production run (Production run-1) was intended to expose problems in the system, with subsequent production runs being improvements. As shown in figure 5.1, individual groups were assigned to work on continuous improvement projects in between production runs. Each of these projects were intended to improve on the prior performance of the system. During each production run the following production related data was collected analyzing the performance of the system:

- Throughput rate for each manufacturing cell
- Number of Defects produced per station
- Work in process (WIP) at each station at the end of the production run required for value stream mapping
- Value added/None value added time at each workstation required for line balancing purposes

- Stock in hand (Raw material stock) at each workstation required for value stream mapping purposes.

5.5 Individual group lean manufacturing project

Three group projects were identified as shown in 5.1. As described earlier production run-1 was intentionally made to be inefficient and it showed in the performance as recorded. Students were not given any instruction on how to run their cells. Students in Cell-1 were subjected to an inefficient changeover process that lasted an average of 5 minutes to complete. Each production run was 45 minutes and the Takt was set at 70 seconds, implying that the expected throughput rate for each cell was 51 cars/ hour.

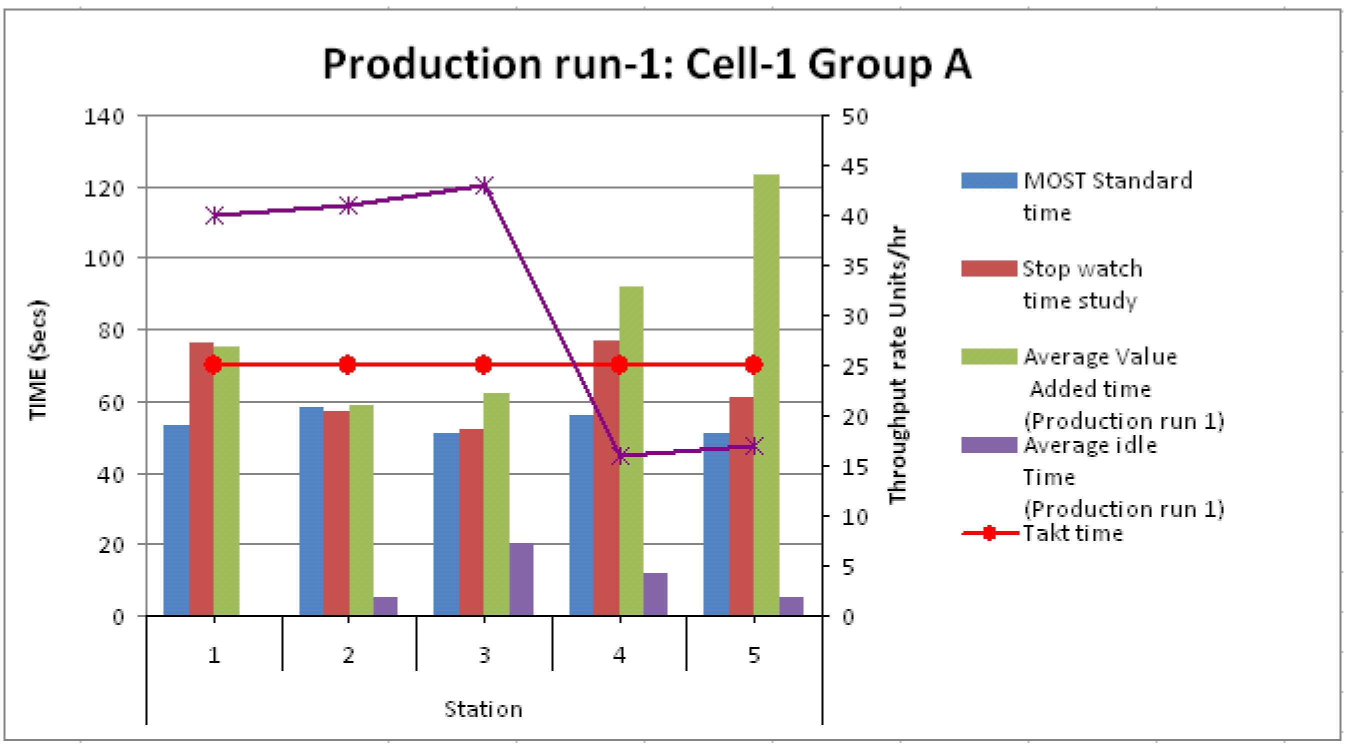


Figure 5.2: Production run -1 results

Figure 5.2 shows the results of Cell 1 during production run-1. It is clearly evident that students in this group ran a push based system as indicated by variation in the throughput rate across stations. Despite the problems at stations 4 and 5, students at other stations kept on assembling products adding to the large amount of WIP at stations 4 and 5. This led to the first group project, of identifying problems in the system. Value stream mapping was selected as the tool of choice.

5.5.1 Value stream mapping Tiger motors (VSM)

One of the important analytic tools used in lean manufacturing is value stream mapping. Value stream is all actions, both value added and non-value added, needed to bring a product through the main flows (Rother & Shook, 1999), and these could be:

- The Production flow from raw material into the arms of the customer
- The design flow from concept to launch

A value stream mapping is a good tool for getting an entire perspective of the operations of an organization, rather than focusing on individual processes that most IE tools do. The Tiger Motors factory provided a foundation for students to learn and actively participate in hands-on, realistic value stream mapping exercise. While students are taught the basic of value stream mapping in a classroom lecture, students are afforded the opportunity to walk the Tiger Motors shop floor and collect data that will enable them to draw the current state value stream for Tiger Motors. By participating in this exercise students were expected to identify all the sources of waste inherent in the value stream. It was expected that by participating in the hands-on exercise students would get an understanding of what value stream mapping is, as well as acquire the skills needed to undertake a value stream mapping exercise. A current value stream map was important for identifying the flows of information and material needed to develop a future VSM. The current state map for Tiger Motors involved collecting production-1 related data and presenting it using a value stream map. Two groups were assigned to this project, (Groups A3 and B3). The current value stream created by the two groups was used as the basis for the development of a future state map.

The current value stream map exercise problem was stated as follows:

Tiger Motors is an automotive assembly plant that is involved in the assembly of two models of vehicles, namely an SUV model and Speeder models. Currently the assembly plant is organized into three departments (under body assembly, cab assembly, final assembly and trim). Switching between an SUV and Speeder requires a 6 minute change over. Management has determined that the forecasted demand for Speeder is 57 900 vehicles per year while the Demand for the SUV is 38 600 vehicles/. The line is expected to operate 50 weeks/year, 5 shifts /per week, 7.5hrs/shift. In addition, the following information from production control was made available:

- Tiger Motors Forecasts 90/60/ 30 day forecasts and enters them into an MRP
- Issues out a 4 week forecasts to its suppliers via MRP
- Secures Raw Material stock from its suppliers by weekly faxed order release to its Customers. Receives Raw materials from suppliers on Mondays and Wednesdays of each week.
- Generates weekly department requirements based on Customer orders, WIP inventory levels, Finished Goods inventory levels, anticipated scrap and downtime.
- Issues daily build schedules to Cell-1, Cell-2, Cell-3
- Issues Daily shipping schedule to Shipping Department.
- The first station of Cell receives Build schedule. When work at station is completed the Subassembly is transferred to the next station. Transfer of work between Cells is done in batches of five. A material handler uses a hand driven cart to transfer completed work pieces between cells as well as replenish raw stock.

Process Information for all cells was collected and recorded by individual group members and recorded in forms provided (see Appendix DataCollection). Station cycle times, scrap rates associated with each station and inventory levels (stock at hand, and WIP) were made available. With this information, the two groups assigned to the VSM project were tasked with drawing a current VSM for Tiger Motors.

Figure 5.3 shows the current VSM for tiger motors submitted by Group A3. It can be deduced from the VSM that quality problems exist in every cell as indicated by the scrap rates at particular stations. The VSM also indicates large WIP buffer sizes between cells. The large buffers were arbitrarily selected for their size to protect upstream processes from being starved, due in part to large setup changes particularly at station 5. Of particular note are the information flows between production control and each manufacturing cell in the form of production schedules. Each manufacturing cell receives a production schedule which is used to sequence vehicles built in that cell. This creates potential for problems of synchronization if schedules are not matched correctly. This synchronization problem is a common problem in MRP based systems, and it was the intent to demonstrate this in the lab by providing slightly mismatched schedules to all three cells. The process ratio for this value stream map is 22%, implying that 78% of the time, a unit spends waiting in queues.

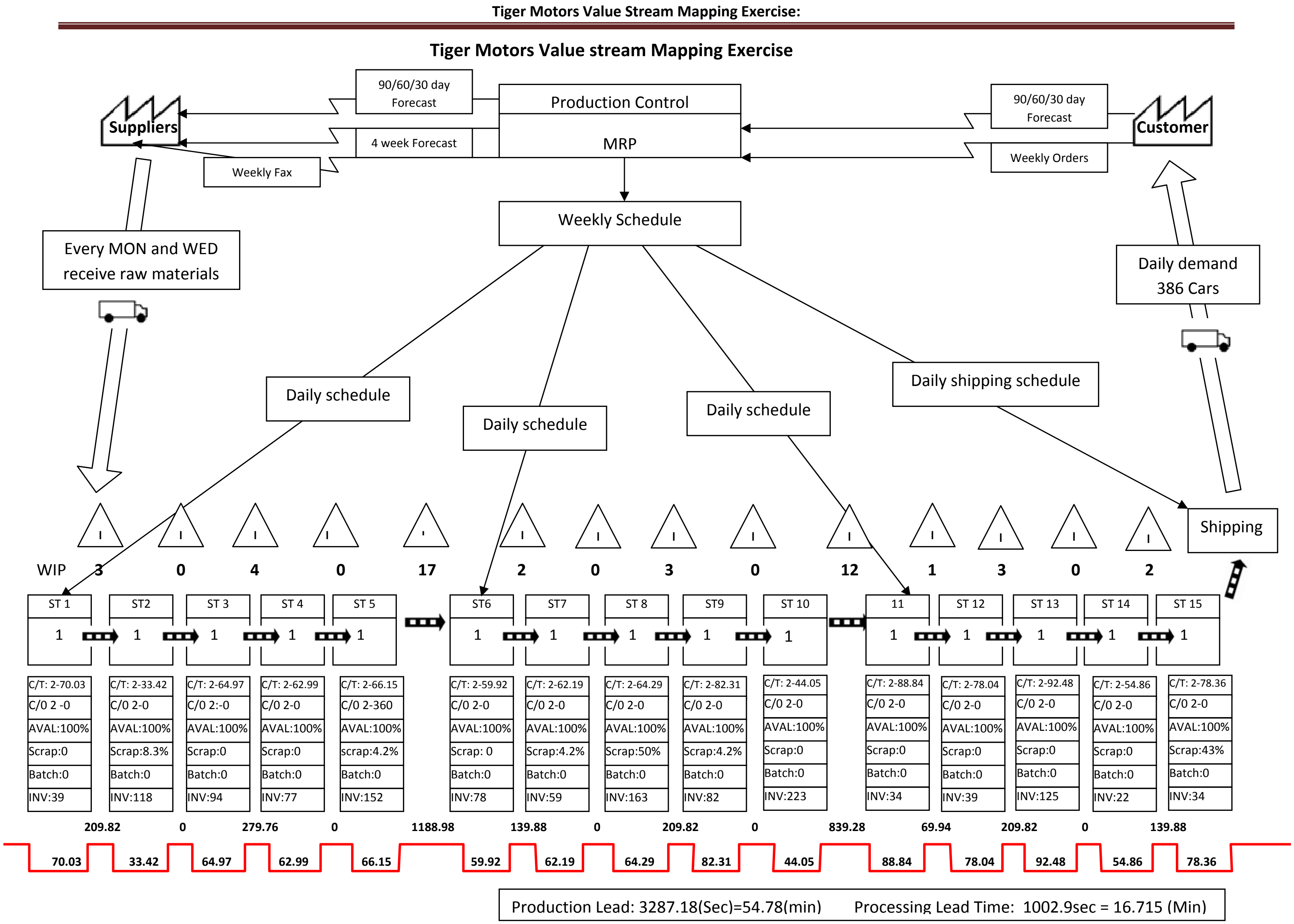


Figure 5.3: Tiger Motors current value stream map

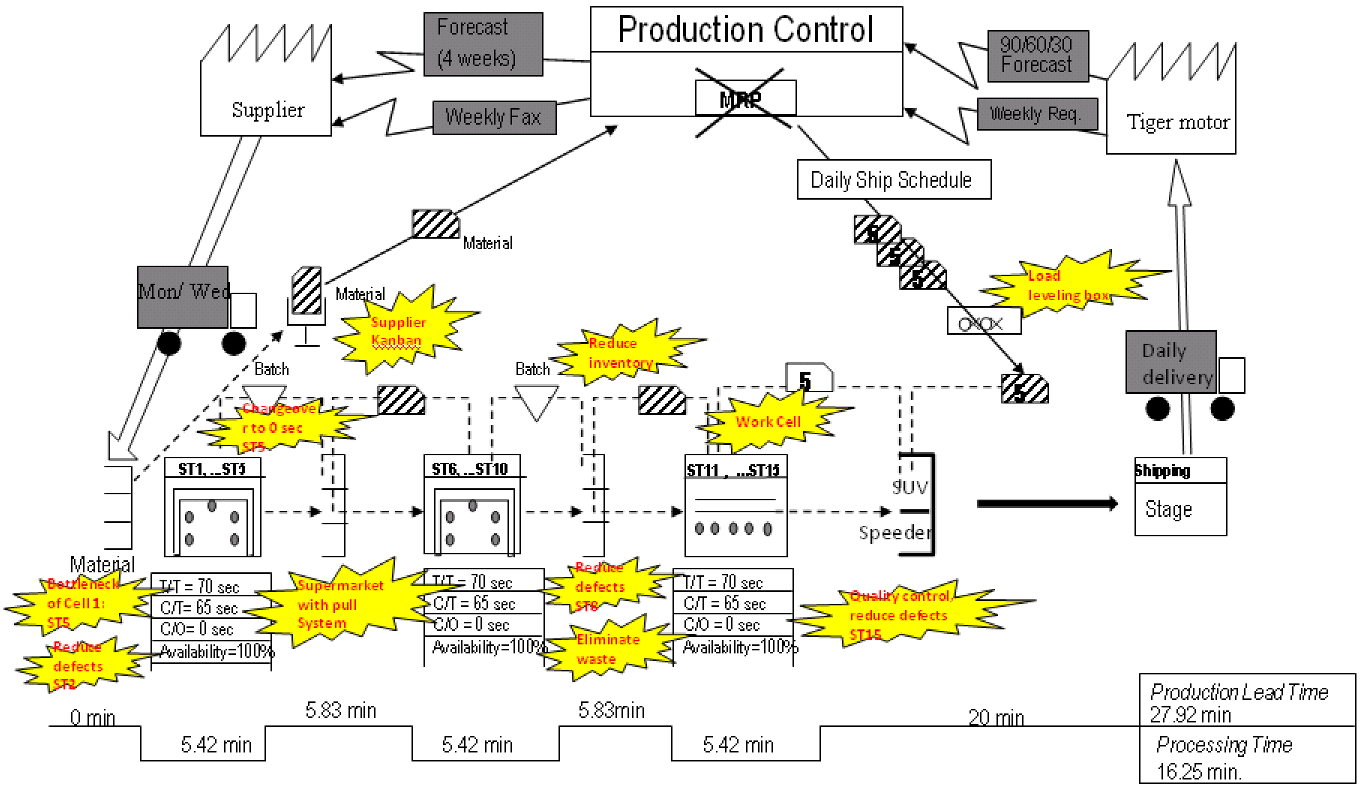


Figure 5.4: Tiger Motors Future Value stream map

Figure 5.4 shows a proposed future value stream map for Tiger Motors. It can be seen from this figure that MRP system was to be replaced with a pull based system where production is scheduled at one point in the value stream (station 15) . This point is referred to as the pacemaker process, because production is controlled at this point and it sets the pace for all upstream processes. As a way of promoting continuous flow, the buffer size within each cell it was proposed to cap the buffer size between stations at 1. However because of the difficulty of maintaining continuous flow between manufacturing cells, a supermarket buffer was proposed . The key decision that had to be made was regarding the size of the supermarket. The size of the supermarket is a function of the bottleneck station and variability in the process time. The future value stream map shown in figure 5.4 shows a proposed supermarket buffer size of 5 between cells. Since it was evident that there was imbalance between stations, it was necessary to use line balancing to ensure that they were below takt time. In order to reduce the size of the buffer between cells, it was necessary to reduce the amount of change over time at station 5 (bottleneck station). It is evident that the reduction in buffer size was expected to have the greatest impact in reducing the manufacturing lead time. By significantly reducing the buffer size, the manufacturing lead time was expected to cut by almost 2/3 of the original value. Figure 5.4 proposed the use of a 2 card Kanban system for controlling flow in the system. Upstream and downstream process are linked by using withdrawal and production Kanbans. A withdrawal Kanban is used by a downstream process to request material from a downstream process, while authorization of production at an upstream process is done using a production Kanban.

5.5.2 Lab implementation of pull based 2 Card Kanban Production Control with production leveling

Figure 5.4on page 149 shows an example of a solution presented by one of the student that particpated in an INSY6800/5800 class. To provide student with more concrete experience, the solution to the problem had to be implemented on the Tiger Motors shop floor. A 2 card Kanban pull system was developed and substituted the push production control system that had previously been in place. The main objectives of implementing this live simulation of pull production system complete with production leveling were:

1. How to implement load leveling using a Heijunka board
2. How a two bin kanban systems for material replenishment works
3. How Kanban system can be used for controlling replenishment of raw material at the workstation. A Two bin system will be used for ensuring that while one bin is sent back for replenishment, the workstation is not starved of parts. The decision is how much raw material should each bin hold.

4. How a flow of Work in process (WIP) in the manufacturing system is regulated by Withdrawal and Production Kanbans.

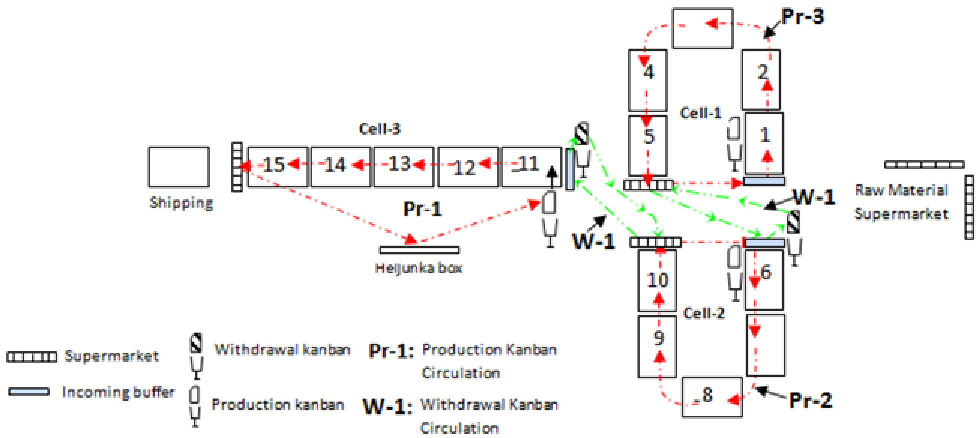


Figure 5.5: Pull Production Kanban loops

Figure 5.5 shows the implemented Kanban loops on Tiger Motor's Production floor. It can be noticed that production and withdrawal Kanban post have been located at the beginning of each cell. An inbound buffer storage area was located at the first station of each cell, while an outbound buffer storage is located close to the last station of each cell. In this particular case the outbound buffer storage is referred to as a supermarket. The number of units of WIP at each inbound storage buffer and supermarket is determined by the number of Kanban cards. The number of Kanban cards in the system determines the total amount of WIP in the system. The number of Kanban cards required in each Kanban loop depicted in Figure 5.5 is a function of replenishment lead time container quantity, as well as the demand rate for that particular product or raw material. This number can be mathematically determined using equation 4.1 given on page 4.1. However, students that took part in this course were not required to establish the number of Kanban cards required in the system, rather the goal was for them to understand how the system worked in controlling WIP in the system. It is also important to make a distinction between the fact that the two card system described is meant for work in process inventory rather than raw stock inventory which uses a different strategy than described here. Each WIP container in the inbound buffer has withdrawal

Kanban attached to it while each full container of WIP at the supermarket has a production Kanban attached to it.

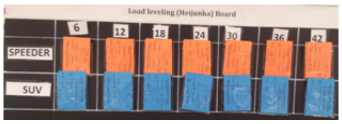


Figure 5.6: implementation of a load leveling using a heinjunka board

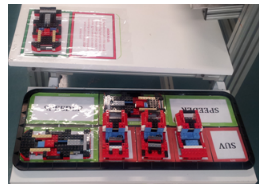


Figure 5.7: Supermarket buffer at the end of Tiger Motors manufacturing Cell

Figure 5.6 shows a Heijunka board used for leveling the load at Tiger motors. The board is divided into equal increments of time (5 minutes) called a pitch. The pitch determines how many of each vehicle should be produced within that period. This time includes the time required to produce parts, changeover time, and expected downtimes. At every interval a material handler retrieves these cards and delivers to the pacemaker process (WK-11).

5.5.3 Setup reduction using single minute exchange of dies

Because of the changeover problem, large batch sizes had to be maintained so that "Cell 1" could keep up with demand requirements of "Cell 2". The effect of setups can be better understood by the equation:

$$\text{Capacity given batch size} = \frac{\text{Batch size}}{\text{Setup time} + \text{Batch size} \times \text{time per unit}} \tag{5.1}$$

In the presence of large setup times, equation 5.1 makes it clear that large batch sizes are necessary to maintain high capacity . However, high batch sizes are undesirable where maintaining flow and meeting customer delivery dates are key objectives. Because of the relatively large setup change relative to the length of simulation run, a change over problem existed. A changeover problem was assigned to two groups (A1 and B1) . The objective for each group was to use SMED analysis tools to establish the inadequacies that existed in the change over setup. After the SMED analysis, with the Lab TA playing the facilitator role, each group was required to develop a solution . Each group was awarded $50 for the purchase of any material needed for implementing the solution. Both teams worked independently to develop the solution to the problem.

SMED analysis of the original setup

In the original setup, the tools and fixtures required to do the setup are located on a shadow board about 30 feet away. Two wrenches and the fixture to be installed are collected from the shadow board. The steps for the change over process are as outlined in table below.

Table 5.1: Pre SMED Analyis

Task Name (elements)	Trial 1 time (sec)	Trial 2 time (sec)	Ext	Int
1. Acquire tools	12.80	10.94	x	
2. Unscrew (4) bolts and Remove (4) bolt from die. Replace old die with new die.	204.86	191.31		x
3. Measure distance SUV: 23 cm & 8.5cm Speedster: 26 cm & 10cm	19.76	17.23		x
4. Place (4) bolts into new die 5. Insert (4) bolts through grate-plate 6. Screw (4) nuts onto (4) bolts 7. Tighten (4) screws	231.65	214.37		x
8. Return tools and die to shadow board	11.39	12.41	x	
Total	480.46 seconds	446.26 seconds		

The changeover process was fraught with difficulties that included the bolts being too long, which thus required too many turns of the nuts to insecure the fixture. The task required two people, and the once the new fixture was put in place it was difficult to align the fixture in the correct position. Table 5.1 shows the breakdown of tasks involved in the the changeover. A key in any change over analysis is the ability to separate external and internal task. It is desirable to increase the portion of time consumed by external task. This is normally accomplished by attempting to change some of the internal changeover tasks into external tasks. It is also clear that the potential for improving the changeover process lay in the removal and installation of the fixture to the table since this consumed almost half of the entire changeover time.

Implemented solution to the SMED problem

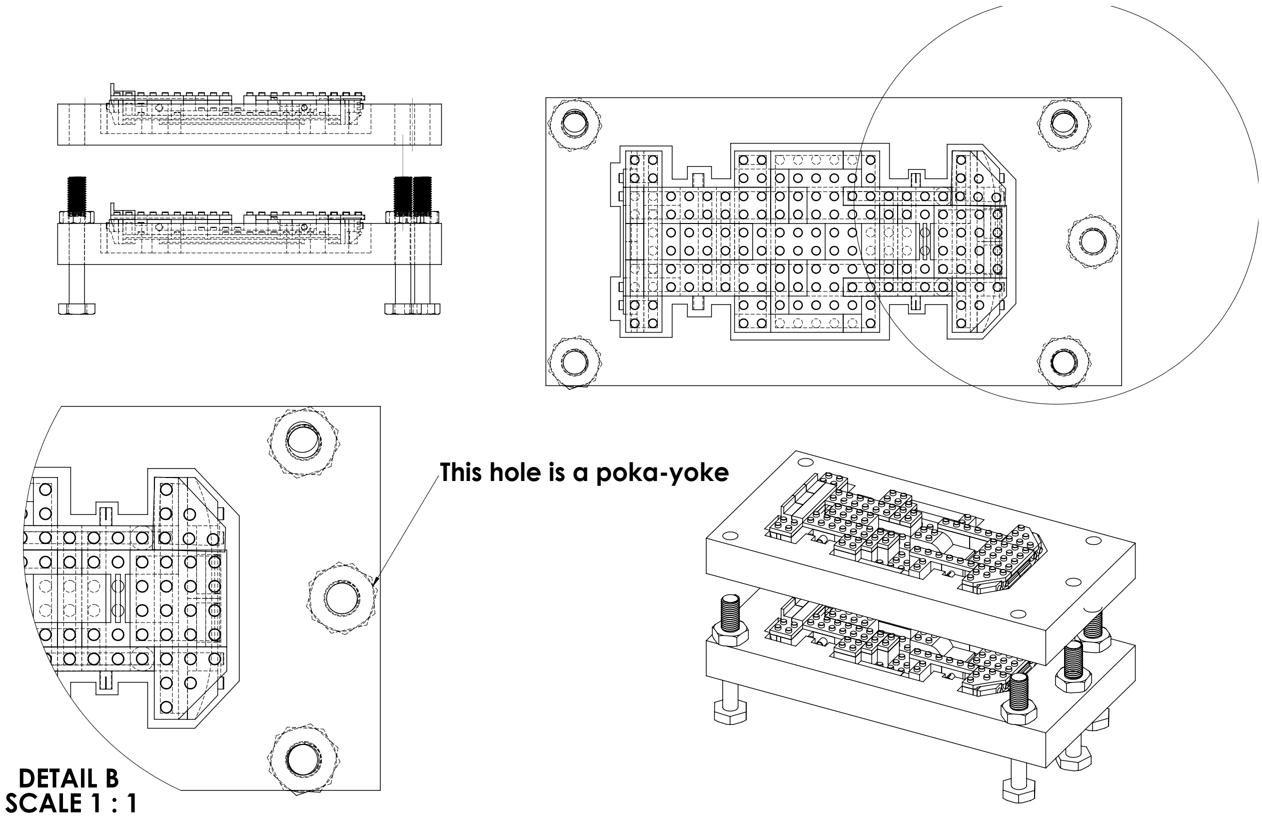


Figure 5.8: SMEDSolution

Proposed SMED Solutiong

In one of the solutions the larger fixture that is used for the speeder is secured to the work surface as a base, as indicated in Figure 5.8. The second fixture was set on top the first fixture when needed. This was done by drilling several holes in the second fixture to fit properly over the first. This design ensured that alignment using a ruler was eliminated. The resultant change over process was reduced to few seconds since all that was required was removal of the top fixture and putting back in place. The poke yoke hole at bottom ensured that the fixture was always oriented correctly.

5.6 Development of a Simulation tool for assisting with Lean production training

In this section we describe the development of a computer simulation model to be used in conjunction with live simulation to assist students with learning both manufacturing systems concepts (INSY 3800) and lean manufacturing concepts (INSY 6800/5800). The main motivation behind the development of the simulation tool is to provide students with alternative analysis and decision making tool to assist them with understanding how the real system works. Because of the large class sizes normally enrolled in the course, it is often not possible to involve all students in all the different hands-on on activities required to reinforce students' understanding of lean manufacturing concepts. For instance, in the lean manufacturing class at Auburn University only a subset of students were assigned to a particular project such as SMED, Cell design, or value stream mapping. As a result, student bemoaned their lack of participation in other activities and often pointed to it as the reason for not grasping the system view of manufacturing system. Computer simulation thus offers an additional learning tool for enhancing student conceptual understanding of the taught concept. With the simulation model developed students will make the following analysis of the system:

- Establish the impact of change over time on system performance
- Investigate the effect of buffers between stations as well as between cells on system performance. The model allows students to answer what if questions. for instance how would increasing the the buffer quantity from 1 to 2 on the system performance. Depending on the change over time at station what buffer size would be adequate for ensuring system throughput is met.
- Determine the impact of changing a system from a push based MRP system to a push system.

- Analyze a particular line balance solution as well as establish a suitable assignment of operators to stations, taking into consideration variability task times between operators
- Based on data on the model, create a value stream map and evaluate future value stream map

During the physical Lego lab simulation several performance measures were taken in to account to determine how well a group of students performed in the Cell that they had been assigned to. The Primary performance measures was the throughput of at each cell. The throughput of each Cell was determined by the number of vehicles produced during the production interval. The second performance measure used was the Throughput time for each Cell. The Throughput times was determined by taking note of the times the vehicle entered the system and the time it exited the system. The The difference between the two times is the system throughput time. In addition, Station utilization was determined by measuring the value added time and none value added time at each station. Using the value added data gathered during the simulation run, Line balance metrics, "Line balance efficiency" , "Balance delay" were calculated.

The Simulation model can provide students with what if scenarios. A simulation model for Tiger Motors lab was developed to provide what if scenarios analysis to help students visualize the impact of certain design decisions related to the manufacturing Cell they had been assigned to during labs. As and example, the computer models should provide insight on the effect of varying station buffer sizes, Supermarket quantities between cells, production batch sizes, and changeover times on system performance. The availability of this model allows students to make educated decisions about how to control production related variables withing their control in-order to maximize system performance. The simulation models was developed are a true reflection of the Tiger Motors shop floor operations. The data gathered during the hands-on physical simulation runs was used for model verification and validation. During running the live simulation runs it was apparent that there was variation in the task times between different operator at each Cell. It thus became apparent that for a group to maximize system performance, it was important that they assigned their personnel to work stations to match the abilities of the individual to the task complexity of that particular workstation. However the groups found it difficult predicting system performance, thus the the development of this simulation model. The labs associated with the Lean Production course (INSY 5800/5800) involved running three iterations of the Tiger Motors Lab, starting of with the traditional manufacturing environment which is based on a push production (MRP) control strategy . Progressive iteration involved introduction of lean concepts such as batch size reduction, single minute exchange of dies, and use of predetermined supermarkets quantities between cells. The development of the lab allows student to experiment with these control variables and noting impact on system performance before actual implementing the changes in hands-on labs simulations.

5.6.1 Developing a computer simulations model to mimic the production operation at Tiger Motors

Two computer based simulation models were developed using Simio simulation software. The first model represented the traditional manufacturing environment based on push MRP production control strategy. The second Simio model created represents the improved lean manufacturing environment in which a number of lean methodologies have been implemented. The traditional manufacturing environments are characterized by the following:

- Large batch sizes.
- Long change over times.
- Unlimited WIP between stations.
- Absence of standardized work leading to large process variation.

- Absence of cross training among the workers.

Lean manufacturing principles are used to reduce the amount of waste in a manufacturing system. Waste is anything that adds cost but no value to the product. Some of key lean manufacturing methodologies essential to lean transformation include: 1) value stream mapping, 2) Set-up reduction through, 3) load leveling Heijunka, 4) Kanban pull strategies among many others. While researchers in lean manufacturing training have pointed the added benefits of physical simulations (Wang, 2005, Bardurdeen et al.,2001, Cudney et.,2010), lean computer assisted lean manufacturing has the ability another dimension to lean training. In this section we describe the develop of a computer based lean training tool, that we be used in conjunction with the physical lean simulation lab described earlier.

5.6.2 Simulating a traditional push based manufacturing system using Tiger Motors floor layout

Lean training started with introducing students to the traditional manufacturing environment that is based on push (MRP) system. A good understanding of the inadequacies of the traditional manufacturing contrasted against expected benefits of implementing lean manufacturing strategies was the focal point for developing lean simulation training tool. In order for this new tool to be effective in imparting lean learning to students, it was important to assume that all students taking part in the lean production course are novices in computer simulation, despite that computer simulation is offered as an elective course in industrial engineering at AU. It was important that the simulation models developed be easy for students to use, and require minimal training on the actual use of the software. This goal was accomplished by using Excel as the user interface for inputting data required by the simulation models. All the parameters and variables needed to be run if the scenarios are input through an Excel user interface and the results of the simulation are fed back to the Excel file for the user to analyze.

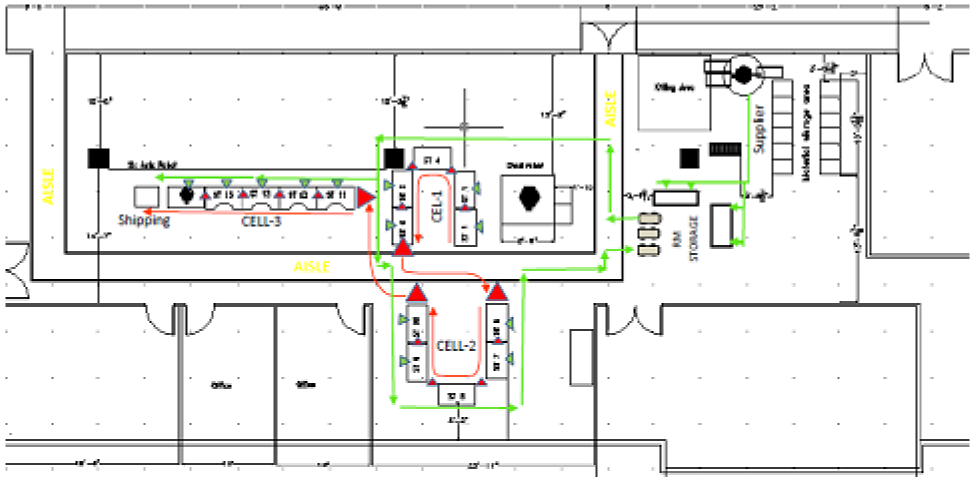


Figure 5.9: Tiger Motors floor layout

Figure shows the layout of Tiger Motors. The manufacturing system is composed of 3 Cells (Cell-1, Cell-2, and Cell 3) as indicated. The flow of material is from Cell-1 to Cell-2 and finally through Cell-3, which is the final assembly Cell. In modeling the traditional push (MRP) system, it was assumed that material is always available at station 1, which is the most upstream of all work stations i.e. this where all production starts. Tiger Motors manufacturing system represents a mixed model assembly line. In the traditional manufacturing environment, WIP between stations is normally uncapped, implying that no restrictions were put on the amount of WIP that can build between workstations. To demonstrate the impact of large change overs, an inefficient change over process was introduced at station 5. Because of the different flow rates within each manufacturing cell, it became necessary to locate a decoupling buffer inventory between the Cells. The simulation model developed allows for the analyst to change all these variables in order to evaluate their impact on systems performance.

Figure shows the Excel worksheet used of inputing work station standard task times needed by the Simio model. It is important to note that the task times at each station can thus be changed to match the specific abilities personnel assigned to a particular station. Each individual can thus be viewed as having their own specific stochastic task distribution,

	A	B	C	D	E	F
1				Cell-1-Processing Time		
2	Parttype	Wk1PrTm	Wk2PrTm	Wk3PrTm	Wk4PrTm	Wk5PrTm
3	SP	random.triangular(54,63,71)	random.triangular(58,63,72)	random.triangular(54,70,76)	random.triangular(50,70,80)	random.triangular(52,62,71)
4	SUV	random.triangular(45,53,61)	random.triangular(50,58,67)	random.triangular(54,63,73)	random.triangular(35,50,70)	random.triangular(36,43,49)
5						
6				Cell-2-Processing Time		
7	Parttype	Wk6PrTm	Wk7PrTm	Wk8PrTm	Wk9PrTm	Wk10PrTm
8	SP	random.triangular(52,62,71)	random.triangular(60,70,81)	random.triangular(57,67,77)	random.triangular(46,53,62)	random.triangular(47,56,64)
9	SUV	random.triangular(43,51,58)	random.triangular(50,58,67)	random.triangular(49,58,66)	random.triangular(62,74,85)	random.triangular(56,66,76)
10						
11				Cell-3-Processing Time		
12	Parttype	Wk11PrTm	Wk12PrTm	Wk13PrTm	Wk14PrTm	Wk15PrTm
13	SP	random.triangular(50,59,68)	random.triangular(50,63,68)	random.triangular(60,71,81)	random.triangular(59,69,80)	random.triangular(61,72,82)
14	SUV	random.triangular(51,60,69)	random.triangular(54,63,73)	random.triangular(52,61,70)	random.triangular(51,59,69)	random.triangular(54,63,73)

Figure 5.10: Excel input for station cycle times

which is established through time studies. This arrangement allows for the judicious assignment of personnel that match each individuals' ability with the complexity of the task. The Simio environment used for developing the simulation model is shown in Figure 5.11, while its 3D representation of the model which allows students to observe the product as it flows through the system is shown in Figure ??.

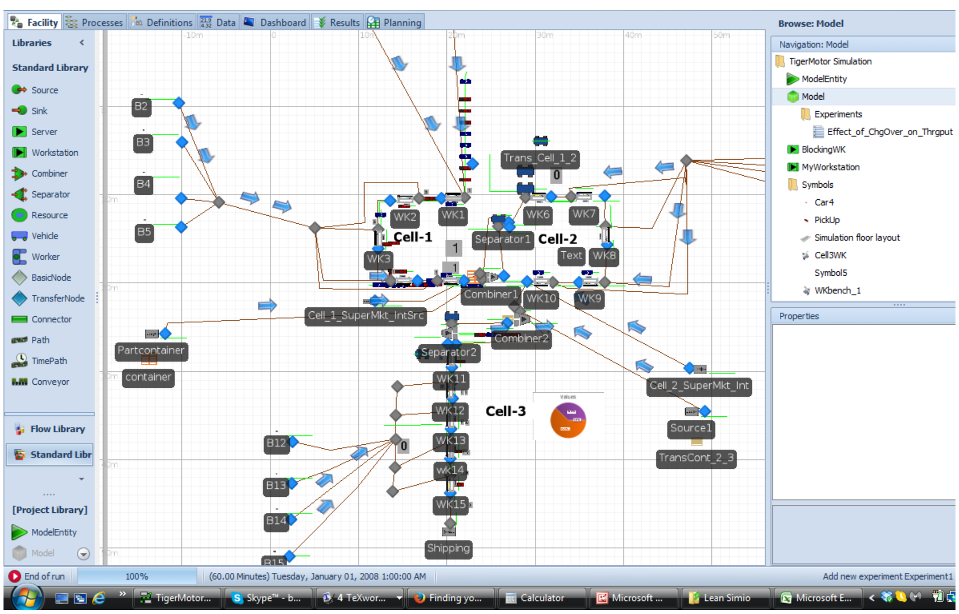


Figure 5.11: Simio development user interface-Push system

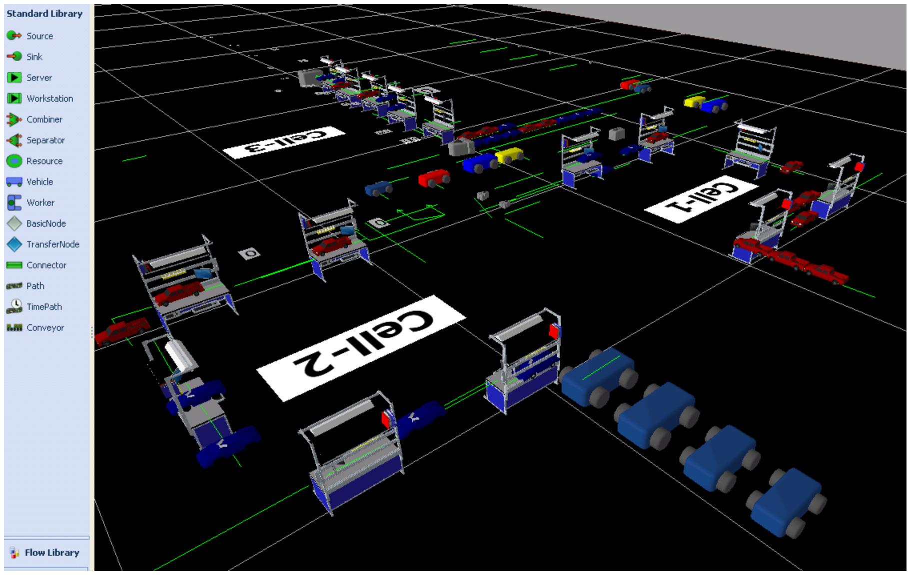


Figure 5.12: 3D-Simio representation of Tiger Motors shop floor

Setting up Simio experiments to enhance students conceptual understanding of the effect of system variable on system performance

Design | Response Results | Pivot Grid | Reports

Scenario			Replications		Controls		
☑	Name	Status	Required	Completed	ChangeoverMatrix	Cell_1_Buffer	Batched_Arrivals
☑	Scenario1	Completed	10	10 of 10	SMED3	Cell1_SuperMkt_IntBuffer.Qty	Arrival_Batch2.Car_Type
☑	Scenario2	Completed	10	10 of 10	SMED3	Cell1_SuperMkt_IntBuffer.Qty	Arrival_Batch2.Car_Type1
☑	Scenario3	Completed	10	10 of 10	SMED3	Cell1_SuperMkt_IntBuffer.Qty	Arrival_Batch2.Car_Type2

(a) Simo experimental setup

	Responses						
	Cell_1_Throughput	Cell_2_Throughput	Cell_3_Throughput	Cell_1_Through_put_Time (Minutes)	Cell_2_ThroughputTime (Min...	Cell_3_Throughput_Time (Minutes)	Lateness (Minutes)
e	42	49	56.4	35.3334	6.77322	5.39293	21.5313
e1	60.4	67.2	74	29.0721	6.84804	5.22596	20.263
e2	83.9	84.8	90.9	22.2607	7.58439	5.307	15.2837

(b) Simio expermental responses

Figure 5.13: Simio experimental setup for investigating the effects .

Figure 5.13 shows the experimental setup for investigating the effect of input batch sizes and change over time on the performance of the system. In addition, the experimental setup allows students to investigate the effect of varying the quantity of buffer material kept between cells that is needed to support interrupted production in Cells 2 and 3 given a production run length. The experimental controls which include change over time(changeover matrix), batch size (entity arrival table), and buffer size are shown in Figure . The experimental setup shown is for the largest change over time (SMED3) across all scenarios, while the batch size was increased with each incremented scenario. The main responses include the throughput, throughput time, and system delays for each cell as indicated in Figure . Delays in this particular case were used as a measure of the system's ability to meet custom orders in a timely manner.

	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1		**Prod Sequence**	**Vehicle type**																			
2		Sequence-1	SP	SP	SP	SUV	SUV	SP	SP	SP	SUV	SUV	SP	SP	SP	SUV	SUV	SP	SP	SP	SUV	SUV
3		Sequence-2	SP	SP	SP	SP	SP	SP	SUV	SUV	SUV	SUV	SP	SP	SP	SP	SP	SP	SUV	SUV	SUV	SUV
4		Sequence-3	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SUV	SUV	SUV	SUV	SUV	SUV	SUV	SUV

Figure 5.14: Batch sequence levels used for investigating influence of batching on system performance

Figure 5.14 represents the levels of batching that were used for demonstrating the effects of batching on system performance. The batch sequences used in the computer simulation was matched to the batch sequences used during the actual hands on simulations done during students' labs. Sequence 1 represents the lowest level of batching (small batches) while sequence 3 (large batches) represents the highest level of batching.

Simio model experimental results for Tiger Motors MRP based system

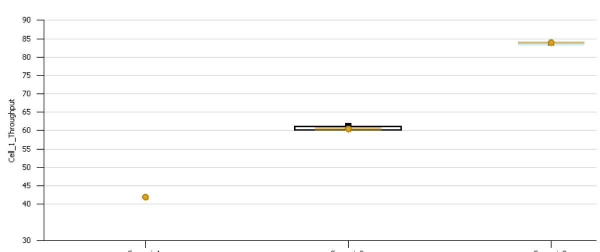


Figure 5.15: Cell -1 Throughput

Figure 5.16: Cell-1 Throughput time

Figures 5.15 and 5.16 shows the results of the experimental setup shown in Figure 5.13 for investigating the effects of changeovers, production run batch sizes, and buffers between stations. The setup shown was used to demonstrate the effect of varying the batch size in the presence of large changeover times. The batch size is increased with each incremental scenario. Figure 5.15 indicates that the smaller the batch size, the less the throughput while throughput time is at its largest as indicated in Figure 5.16.This experimental set-up provides a good teaching tool that can be demonstrated by the mathematical concepts related to the determination of optimal batch sizes given change over time . By changing experimental controls , the relationship between the variables (batch size, change over time, and station buffers) and their response variables (throughput, throughput time, and Lateness) can be investigated promoting a better understanding of the theoretical concepts . A good example is the relationship between batch sizes, change over time, buffer quantities, system throughput, throughput time, and Lateness. Lateness in this particular case was defined as the difference between the time when a customer places and order and when the order is met. Comparisons may also be made between the two models, one representing the a push MRP system and the other representing a pull based lean manufacturing production strategy.

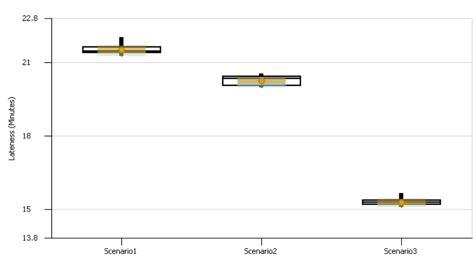


Figure 5.17: Effect of batching with large change over times exist

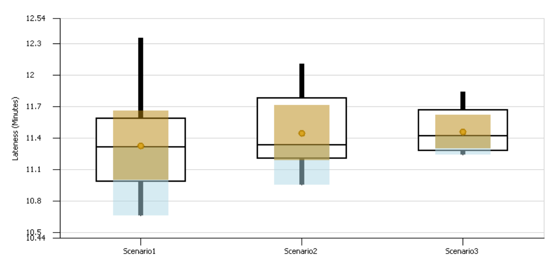


Figure 5.18: Effect of batching with small change over times exist

Figure 5.17 shows the effect of batching in the presence of large changeover times. Small batches resulted in more late orders and this is attributed to the reduced throughput rate in the system. On the other hand, Figure 5.18 shows the impact of significantly reducing the changeover time. The smaller the batch size, the less tardy orders are, as shown in Figure 5.18.

5.6.3 Simulating a Lean based production manufacturing system using Tiger Motors floor layout

The lab component of the lean production course (INSY 6800/5800) involved a number of iterations in which students' lab assignments began with a production system characterized the inadequacies normally associated with such systems as described earlier. The implementation of lean manufacturing methodologies is intended to overcome the inherent inadequacies of the tradition manufacturing. By developing a second simulation model that integrates some of the lean manufacturing philosophies, we are able to demonstrate and quantify the benefits of lean manufacturing approach in a virtual environment to the benefit of the student learner. A second model representing a pull production system was developed . The major differences from the push based MRP model developed earlier were as follows:

1. buffers between stations is capped. The input buffer status of downstream process establishes processing capability of its next upstream process.

2. A supermarket buffer was introduced to decouple downstream cells from up stream cells.

3. A two bin Kanban system was introduced to control the flow of material between cells.

4. A load leveling strategy (Heijunka) was implemented to smoothen out the fluctuations in demand over the predetermined time period (lab time).

Implementation of a pull production control system for Tiger Motors using Simio

In order to cap WIP between adjacent upstream and down stream station it was necessary to model severs (workstations) that could communicate with each other. To accomplish this, each workstation was modeled to shut down or become blocked when there was no room in the downstream buffer. Two properties were introduced to each sever, Max buffer size (**MaxbufferSize**) and Minimum buffer size (**MinbufferSize**) . The Maximum buffer property determines the maximum size of the WIP allowed in the downstream buffer, while the minimum buffer property established the minimum amount of WIP that had to be reached to unlock the server.

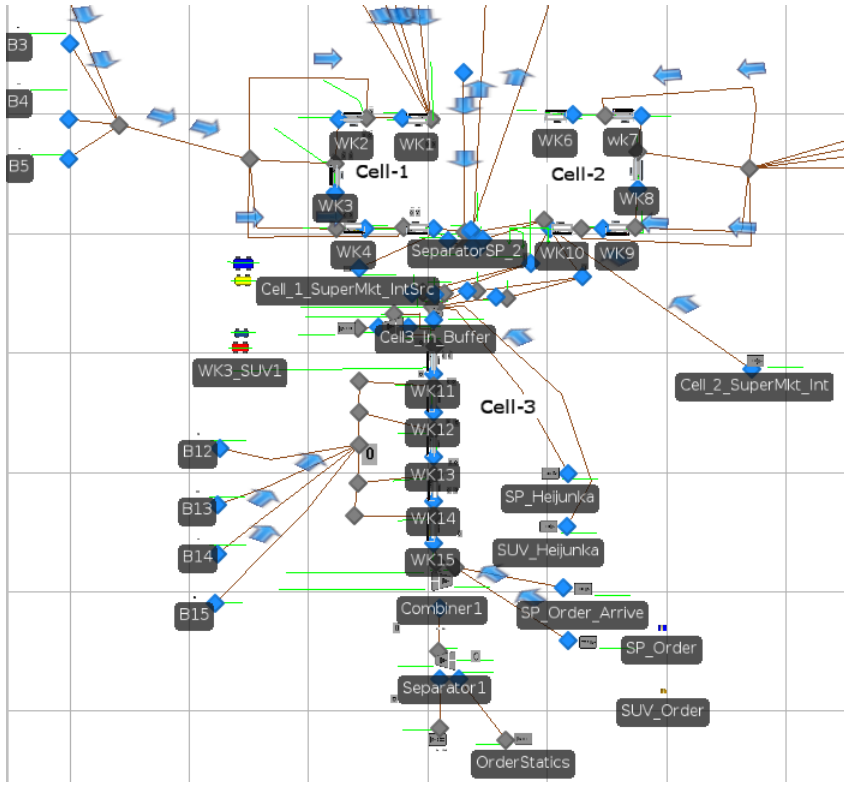


Figure 5.19: Simio model of Tiger motors pull based production control system

Figure shows the pull kanban based implementation of Tiger Motors shop floor using Simio simulation software. Differences between the pull system (Figure 5.19) and the push MRP system (Figure **??**) are evident from the two figures representing each system. The absence of a heijunka in Figure 5.12 is the major difference between the two systems. In order to model a heijunka box, a source was used that sequenced production Kanbans. A (**Source simio object**) was used for producing these sequenced production Kanbans. Entity arrivals at the source is done using a reference table, which contains the leveled production entities representing the 2 models of vehicles, the SP and SUV respectively. Workstation 11 (WK11) was selected as the pacemaker process in this particular case. Production Kanban cards from the SP and SUV Heijunka sources are queued at the pacemaker process. Using a **Combiner simio object**, each Kanban card at the source is matched with the appropriate model of vehicle, thus controlling the sequence of vehicles produced at WK-11. This implementation results in a leveled production (Heijunka).

Two **Seperator Simio objects** were used at the end of Cell-5 to create signals authorizing the replenishment of material to WK-1. Whenever an vehicle (entity) is withdrawn from the Supermarket, a copy of the entity is created by the **Seperator**. This copy of the entity serves as signal for the source to replenish a similar entity to WK-1, thus accomplishing the pull. A transporter is used to transfer material from the supermarket to the input buffer queues of the first station of the downstream cell. Each input buffer queue is for a particular vehicle and can only hold a predetermined number of vehicles (entities). A **Monitor element** was used to monitor the size of the queue . Based on the predetermined minimum and maximum size of each queue, the transporter is disabled or enabled for pickup of vehicles (entities) from the upstream supermarket, thus accomplishing capping of WIP at the input buffer of first workstation in the downstream Cell.

Tiger Motors pull system model verification and results in Simio

As a way of verifying the model, an experiment was setup in which the control variables included the change over time, maximum/minimum buffer size between adjacent workstations, and the size of the supermarket at Cell-1. Three change over times (Scenario 1:40 seconds, Scenario 2: 120 seconds, Scenario 3: 300 seconds) were investigated.

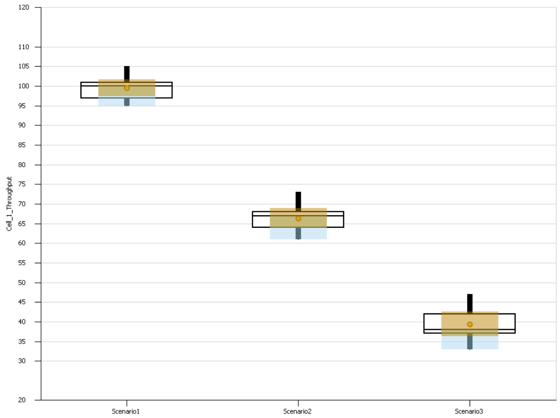


Figure 5.20: Cell-1 throughput

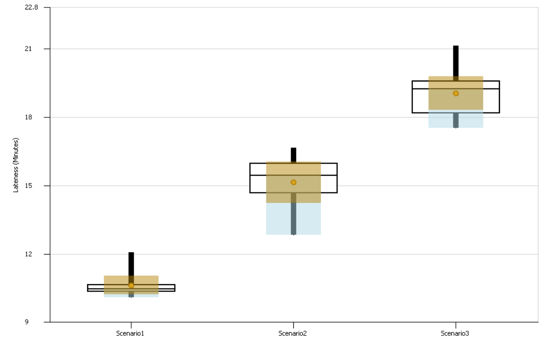


Figure 5.21: System Lateness response results

Figures 5.20 and 5.21 shows the throughput of Cell-1 and system lateness respectively. The results generated were as expected, thus verifying the efficacy of the model. When the changeover time is high, the throughput of Cell-1 is low, implying that without an adequate supermarket quantity at the end of Cell-1, downstream processes in Cell-2 and Cell-3 are starved of input material, and consequently customer orders are not met in time as indicated in Figure 5.21. In addition, the use of computer simulation for modeling the two production strategies, push and pull can be used for comparing the two strategies under the same conditions. The lean production strategy resulted in less tardiness of orders when compared to the traditional push strategy under the same condition (see appendix G)

5.6.4 Discussion and Conclusion

Virtual learning offers an alternative and less costly alternative to hands-on training of lean manufacturing concepts. While live simulations are normally time consuming and are team oriented exercises, the use of computer simulation can be an added benefit as students can experiment with different ways in which to set up the lab prior to attending the live sessions, thus reducing confusion normally associated with introduction to labs. By making the computer simulation available to students prior to attending the lab, a structured assignments could be given in which students would required to input predetermined parameters as input to the simulation model. Students would then be able to relate system performance to experimental variables used. It is from this individual experiments that conceptual understanding begins and is further reinforced through live simulations during labs. Such an undertaking is equivalent to a pre-lab which is intended to prepare students for more rigorous lab work involving live simulations.

Although the two computer simulations models appear to be valid representation of Tiger Motors operations based on simulation results, there is need to carry out a usability analysis of of the two models before they are deemed appropriate as a learning tool for students. A survey will need to be developed to capture students' perspective relating to the use of the two models as a learning tool for enhancing lean manufacturing conceptual understanding. It should also be emphasized that the use of computer simulation can not solely be used as an effective method for lean manufacturing training but should used in combination with live simulation for a more comprehensive understanding of lean manufacturing concepts.

5.7 An Assessment of the effectiveness of hands-on laboratory participation in enhancing student learning

5.7.1 Methodology

One of the important goals of this research was to establish whether integrating manufacturing laboratories in manufacturing curriculum does enhance students' learning, and thus a student's body of knowledge. If this can be proven true, then this knowledge can be used as motivation for development of appropriate laboratory exercises in manufacturing education. This is particularly important for those topics in manufacturing that have lacked the hands-on component to reinforce learning. Hands-on manufacturing labs designed to support Manufacturing Systems course (INSY 3800) and Lean Production courses (INSY 6800/5800) at Auburn University were evaluated to determine their effectiveness in enhancing students conceptual understanding of the subject matter. Students in INSY 3800 courses were undergraduates in their Junior and Senior level of their studies. The INSY 6800 course is offered every Fall semester and typical enrollment for the course is around sixty students, while INSY 3800 is offered in Spring and has thus an average enrollment of ninety students. The INSY 3800 consists of a lecture as well as 10 compulsory labs sessions designed to reinforce lecture material. Students in the course were compelled to attend all lab sessions but were allowed two excused absences without being penalized. The INSY 6800 course was designed to be a lecture only course. However, the instructor for the course required that students acquire some hands-on lean manufacturing experience by engaging in laboratory activities. Because INSY 6800 did not have a lab component, and the lab can only accommodate a maximum of 30 students at any one time, it was difficult to accommodate all sixty students. This problem was overcome by equally dividing the class into two larger Groups that A and B. A and B are the lab groups that attend the lab at the same time. The groups were further subdivided into three smaller groups (Grp 1, Grp2,and Grp 3) of no more than ten members. It is important to note that students were randomly assigned to the groups and each group consisted of at least three graduates students. Each group was requested to nominate a team leader, whose responsibilities included coordinating all lab activities. On designated days either group A or B would be required to attend a lab session to participate in a designated activity, while the other group attended the lecture. Whatever group was designated for a lab activity could still participate in the lecture by watching a recording of the lecture. The event calender for the activities associated with INSY 6800 are shown in 5.1 on page 141.

5.7.2 Evaluation of student outcomes through written test assessment

In order to evaluate the effectiveness of hands-on labs on students learning, an experimental design was conducted. The experimental design required that students be divided into groups as depicted in 5.1 for participation in predetermined hands-on learning activities related to the classroom lecture. All groups participated in three simulated factory production runs (run1, run 2, run 3) which essentially are live simulations of an assembly production line as already discussed in an earlier section of this project. The production runs are designed to demonstrate the incremental improvements that can be made to an inefficiently designed manufacturing system as it evolves from a classical/traditional push manufacturing systems towards a much more efficient leaner manufacturing system. In-between production runs, a student group as depicted in Figure 5.1 was assigned to a lab project that had to be completed before the next production run. Each of the lab projects assigned were intended to add value to the system by improving it through the use of industrial engineering tools. A total of three different lab projects were identified and for each lab project, two groups out of six groups were assigned. A written test covering the topics that included the lab project was then given at the end of the period to assess students' understanding of the topic and developed skills 5.1.

5.7.3 A survey to assess students attitudes and perceptions towards lean manufacturing hands-on laboratory learning

At the end of the Fall 2012 semester a survey was carried out to determine students' perception of learning associated lean hands-on activities associated to the lean manufacturing class (INSY 3800). A total of fifty students out of a possible sixty students were able to participate. The data used in this analysis represents students who answered all survey questions and also signed an informed consent statement that was approved by the Institutional review board at Auburn University. Student's responses were anonymous and the results were analyzed after the completion of the course. The survey instrument used was Qualtrics on-line software. 80 % of the questions required students to respond using a Likert scale to indicate their agreement with particular statements in the question. Of the students that participated in this study, 50% were undergraduate seniors and 50%were graduate students. 76% of the students were male while 24% were female. All students that participated in the study were 20 years and above.

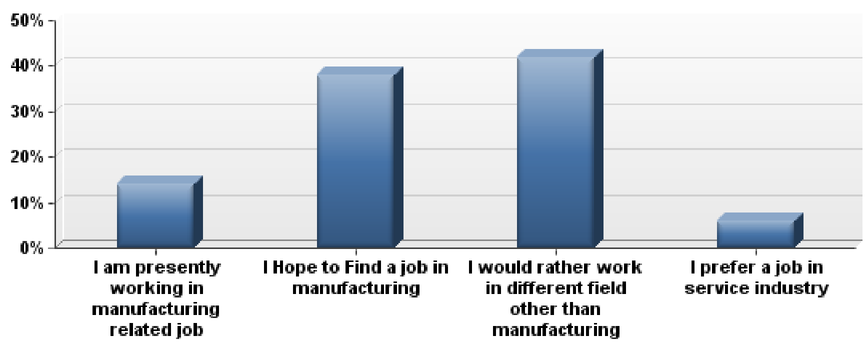
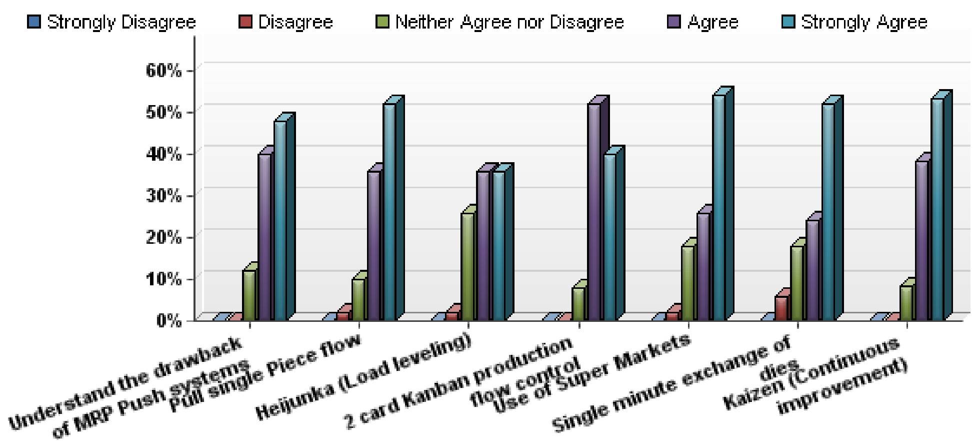


Figure 5.22: Current job positions and expected career paths

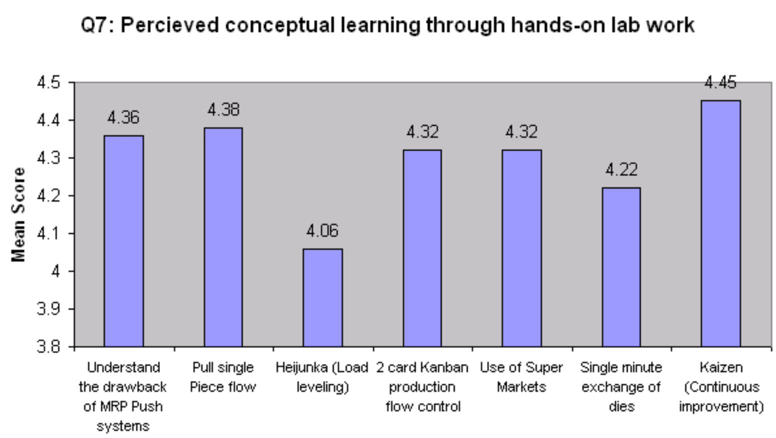
About 50% of students participating in the survey were either already employed in the manufacturing industry or hope to find a job in manufacturing.

Question 7: Students' perception of how the lean manufacturing hands-on activities helped them grasp lean manufacturing concepts taught in the lecture were solicited. Using a Likert scale with 1 being strongly disagree and 5 being, strongly agree, participants were required to indicate their agreement with 5 statements regarding the perceived effect of the hands on lab activities on their learning of lean manufacturing concepts. In this question students were asked to indicate their agreement with the following statement:

statement 1: *feel that participating in the hands-on individual Lean Production Labs helped my understanding of the following Lean concepts better than traditional classroom lecture alone would have done.*



(a) perceived learning



(b) Percieved learning

Figure 5.23: Students perceived learning when participating in hands-on lab activities

Figure 5.23 shows student's response to statement 1. Students perceived the continuous improvement of hands on activity as one that offered the most benefits with respect to learning when compared to lecture alone. Students also found the labs helpful in enhancing their understanding and grasp of concepts related to the distinction between pull and push systems. However, students had ranked the load leveling as the concept that the lab did the least to enhance their understanding, despite the fact that more than 70% of the students did agree that they felt that particular lab was helpful in enhancing their understanding.

Question 8: This question sought to get feedback on how important each hands-on lab activity was as viewed by students. Using a 7 point Likert Scale (1: Not at all important and 7: extremely important), students had to respond to the question:

From experience with the Lean Production Course you just participated in, provide a perspective as to how necessary it is to include the following hands-on activities to supplement classroom lectures for deeper learning and understanding to occur.

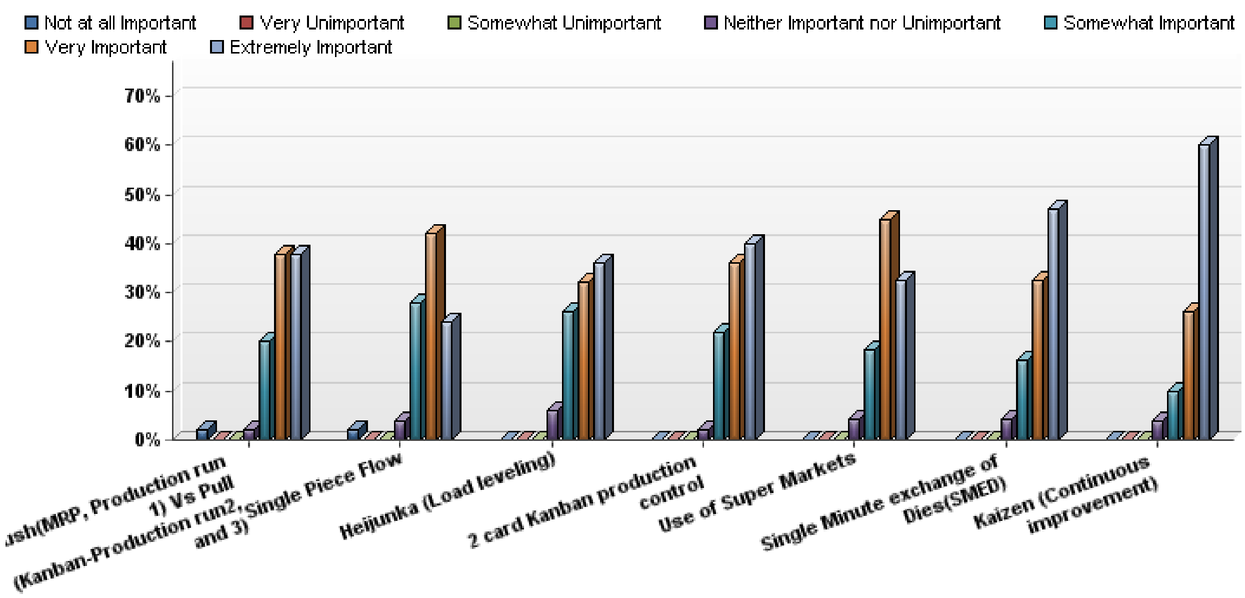


Figure 5.24: Perceived importance of lean lab elements, Q8a

Responses indicated that continuous improvement hands-on lab was considered to be the most important of the hands-on learning activities, followed by Single Minute Exchange of Die(SMED) hands on lab, implementation of Kanban system, and simulating push and pull system (Figure 5.25).

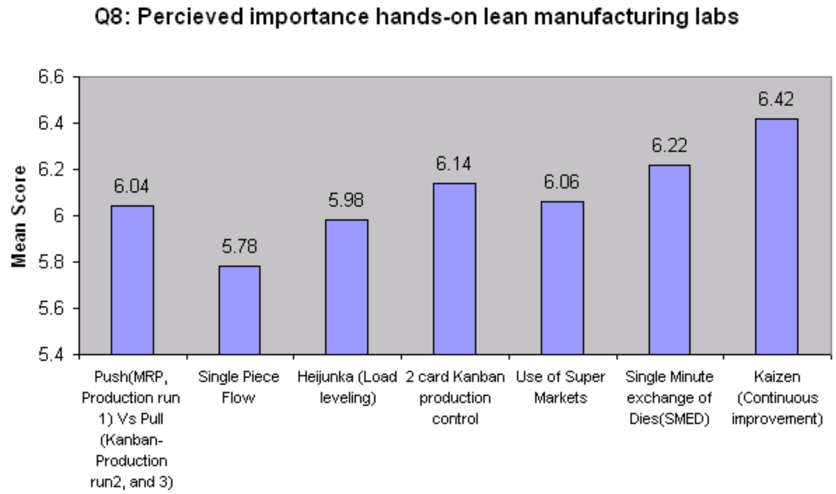


Figure 5.25: Perceived importance of lean lab element, Q8b

Question 9: From the following list of hands-on activities associated with the Lean Production course, rank each activity according to which offered you the best learning experience with regards to enhancing your understanding of Lean Manufacturing concepts. Figure 5.26 shows the responses for this question which indicated that continuous improvement lab and SMED were viewed as offering the most learning of all activities.

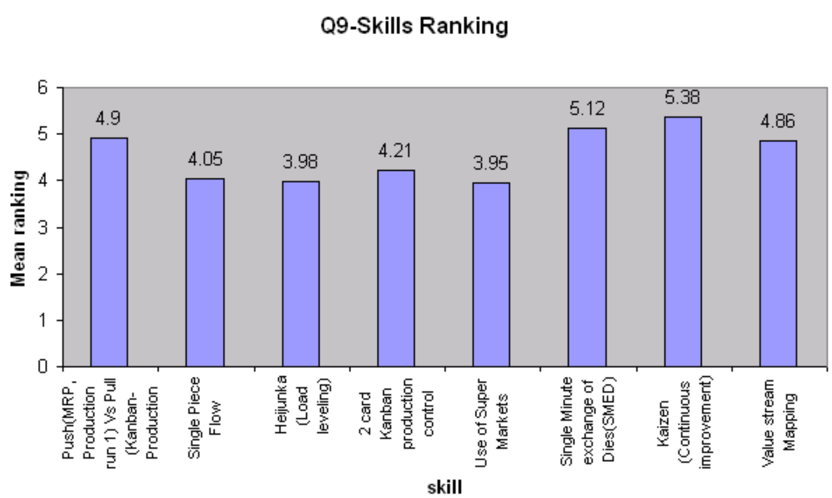


Figure 5.26: Ranking of hands on lab activities according to the best learning experience offered

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Question 14: In this question, respondents had to state their level of agreement with three statements regarding how they perceived their participation in hands-on lab activities and if they were benefited in respect to raising their interest level in the topic taught in the lecture as well as helping them relate classroom theory to practice. Figure 5.27 shows the results of students' responses to the statements. The results showed that a majority of the students (around 80%) felt that participating in hands-on labs helped raise their interest level in the subject being taught in addition to helping them relate taught theory to practice.

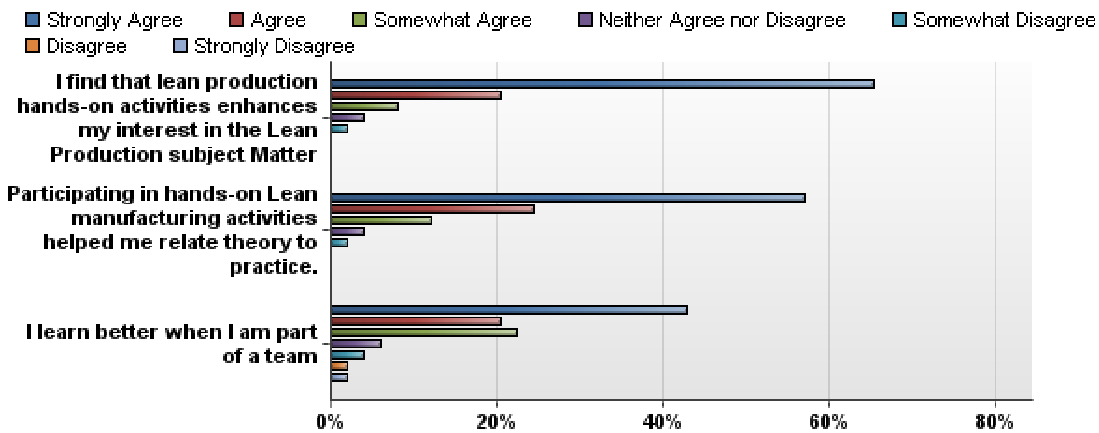


Figure 5.27: benefits of hands-on lab participation with respect to interest level

Question 11: The lean manufacturing class was offered to outreach students who were unable to attend to any hands-on lab activities. As a means of getting outreach students' participation in labs, all hands-on labs were video recorded. This enabled the outreach students to participate in the labs by watching the videos and later responding to questions posted as part of their lab assignment. To assess the effectiveness of this method of involving outreach students, a question was posed to outreach students in which they had to state their agreement with a particular statement (see figure 5.28).

Outreach students' responses were positive, with a majority of the students indicating that they were able to clearly follow the live simulated production runs. Students also indicated that the live production runs also provided a good learning experience that related well to the topic taught in class.

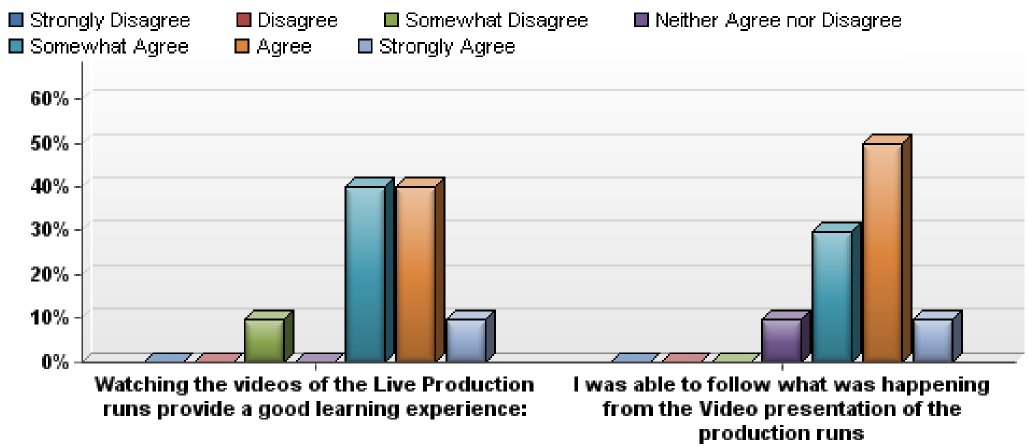


Figure 5.28: Long distance lab participation through video streaming

5.7.4 Discussion

By gathering feedback from students about hands-on lean manufacturing exercises that they participated in, we were able to identify areas that benefited the students the most and also identified areas that needed improvement. In the lab, students had the chance to work in a team environment which allowed to them solve problems as a group, it was thus not surprising to note that students perceived continuous improvement lean manufacturing hands-on leaning activity as the one they felt benefited them the most with regards to learning (Figure 5.25). Students also reported relatively high scores for perceived learning in relation to understanding the difference between MRP push based and pull based production control systems. However it was interesting to note the relatively lower perceived benefit to learning associated with Heijunka load leveling and single minute of exchange of dies aspects of the lab. The relatively low score associated with Hiejunka load leveling may be attributed to the less than adequate involvement of the students in the implementation and installation of the Heijunka load leveling system. Heijunka load leveling was demonstrated to the students physically, but it is possible that its benefits on system performance to a large extent went unnoticed by students. Therefore, while the Heijunka system was in place and students knowingly or unknowingly interacted with it, it is possible that not much may have been done to showcase its benefits on system performance. The survey response to question 1 may indicate the presence of a positive correlation between students' perceived benefit of a hands-on topic and students' active participation related to the topic. It appears that the more students are actively involved through hands-on learning activities, the more likely they view that topic as benefiting their overall understanding. This is evident by the low scores that the SMED and Heijunka hands-on aspects of the lab received by students (figure 5.25).

With more educational institutions offering outreach courses, it's always a challenge to offer laboratory hands-on learning activities to outreach students. In this lean manufacturing course, outreach students successfully participated in hands-on activities through watching videos. Although the outreach students did not actively participate in the hands on labs, the lab video enabled them to participate in all the lab assignment that regular full time students were assigned.

5.7.5 Conclusion

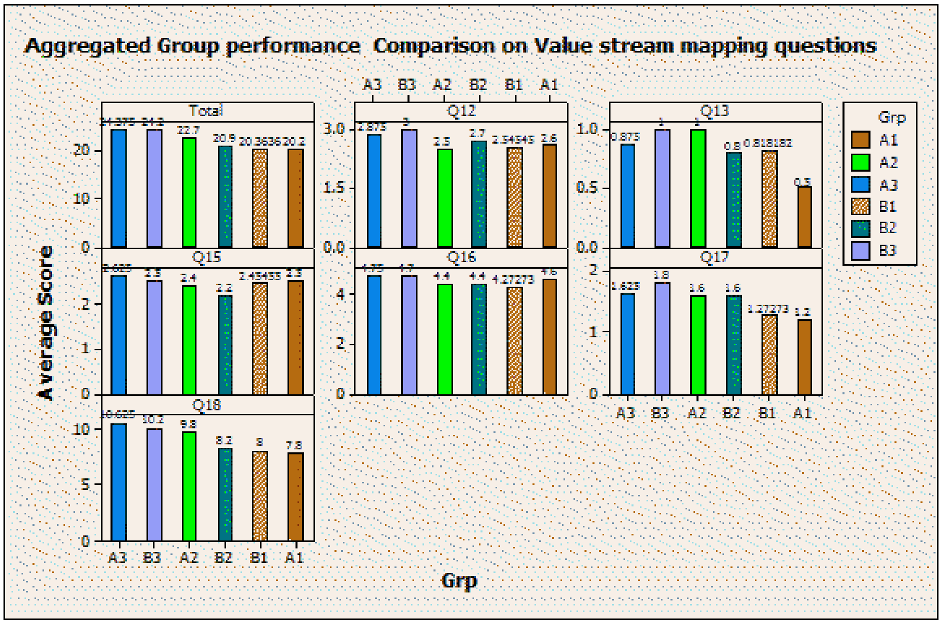
Students perceptions show that laboratory hands-on activities are viewed positively by students. Hands-on labs can offer valuable learning to students by providing an alternative viewpoint from that offered in the classroom. By offering hands-on labs students not only learn about the tools taught in class but get the opportunity to put into practice, thus helping them develop particular problem solving skills as well as improving their confidence in the application of appropriate industrial engineering tools. Indications from students' surveys were a strong indicator that hands-on learning is a necessary activity required to close the competency gaps of manufacturing engineering students.

5.8 Evaluating the effect of hands-on laboratory participation on students conceptual understanding through written tests

Besides students' perceptions on the value of laboratory participation on their conceptual understanding, testing students through tests and quizzes offers one way in which the value of having students participate in labs can be evaluated. To evaluate the effectiveness of laboratory as an add on for reinforcing classroom learning, periodic test were given to students as discussed in section and depicted in Figure 5.1 on page 141. Since students were divided into six project groups with two groups participating in hands on projects related to topic that was been taught at the time, the objective of the exercise was to determine if students that participated in projects had better understanding of the topic compared to those that only received instruction through lecture alone. Three different projects related to Lean Manufacturing were selected and assigned to groups as outlined in Figure 5.1.
. A control treatment experimental approach was taken in which the treatment group participated in both the lecture and project.The objective of this experiment was to determine if involving students in hands-on learning contributed to better understanding of the concepts taught in class. The rationale being that the more active students are involved through projects the deeper learning occurs, and if this deeper learning does indeed occur it should be evident in students' assessment.

5.8.1 Evaluating the performance of treatment group(SMED Lab participation) against control group(None participation in SMED lab

Value stream mapping was the first topic that was covered in classroom lecture and assigned as a project to the two groups. The details of this project were outlined in section 5.5.1 on page 145. After completion of classroom lecture, as well as the hands on value stream mapping exercise (VSM), assessing students' understanding of the topic was conducted by giving out a test. The test consisted of a total of eighteen questions with seven questions related to Value stream mapping. The composition of questions used to assess students understanding is provided in appendix F.1. Aggregate scores for each group were then determined and compared using the generalized linear model ANOVA analysis. Figure 5.29(a) shows the average performance of each group with respect to a value stream map test question. It's apparent from the graphs that scores for groups A3 and B3 appear greater than those of other groups. To determine how significant this difference is requires the analysis of variance study to be performed. A general linear model with two factor at 2 levels each was used for the analysis. The first factor (treatment) represents lab participation coded 1 for non participation and 2 for participation. The second factor (student type) represents the level of each student, coded as 1 for undergraduate student and 2 for graduate student. A fixed factor crossed GLM experimental design was thus used to assess the effect of lab participation on test scores. Figure 5.29(b) shows the results of ANOVA analysis using question 18 as the response variable and lab participation as the factor at two levels. The two levels considered were none participation in hands-on VSM lab as one level and participation in hands-on VSM lab as other level. Since the number of participants at at each level were different a general linear model (GLM) was used for analysis.



(a) Group performance Comparison with respect to VSM test questions

General Linear Model: Q18 versus Treatment, Studentype

```
Factor                 Type   Levels  Values
Treatment              fixed       2  1, 2
Studentype (Treatment) fixed       4  1, 2, 1, 2
```

Analysis of Variance for Q18, using Adjusted SS for Tests

```
Source                 DF   Seq SS   Adj SS  Adj MS     F      P
Treatment               1   47.557   43.778  43.778  5.49  0.023
Studentype(Treatment)   2    0.167    0.167   0.084  0.01  0.990
Error                  55  438.208  438.208   7.967
Total                  58  485.932

S = 2.82266   R-Sq = 9.82%   R-Sq(adj) = 4.90%

Unusual Observations for Q18

Obs     Q18     Fit  SE Fit  Residual  St Resid
  5  1.0000  8.4643  0.5334   -7.4643     -2.69 R

R denotes an observation with a large standardized residual.
```

Dunnett 95.0% Simultaneous Confidence Intervals Response Variable Q18
Comparisons with Control Level

```
Treatment = 1  subtracted from:

Treatment    Lower  Center  Upper  -------+---------+---------+---------
2           0.2890   1.992  3.695  (----------------*----------------)
                                   -------+---------+---------+---------1.0
2.0       3.0
                                          1.0       2.0       3.0
```

Dunnett Simultaneous Tests Response Variable Q18 Comparisons with Control Level

```
Treatment = 1  subtracted from:

           Difference      SE of            Adjusted
Treatment    of Means  Difference  T-Value   P-Value
2               1.992      0.8499    2.344    0.0227
```

(b) Analysis of variance for Q18

Figure 5.29: Comparing group performance with respect to specific VSM test questions

The ANOVA F-test indicates that with respect to Q18, there is significant evidence for hands-on lab participation (treatment) effects (p-value =0.023). The confidence interval for difference in means between the treatment and control group does exclude zero, thus indicating a significant difference between the treatment group and control group means. Dunnet's confidence interval comparisons indicates that the treatment group mean is higher than the control group.

Analysis of Variance for total for Value stream mapping

Q16

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	1.1834	1.4616	1.4616	3.79	0.057
Studentype(Treatment)	2	0.3288	0.3288	0.1644	0.43	0.655
Error	55	21.2335	21.2335	0.3861		
Total	58	22.7458				

Q15

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	0.3418	0.1377	0.1377	0.38	0.538
Studentype(Treatment)	2	0.4460	0.4460	0.2230	0.62	0.541
Error	55	19.7546	19.7546	0.3592		
Total	58	20.5424				

Q12

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	0.3363	0.4477	0.4477	3.16	0.081
Studentype(Treatment)	2	0.1758	0.1758	0.0879	0.62	0.541
Error	55	7.7930	7.7930	0.1417		
Total	58	8.3051				

Total

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	210.99	215.26	215.26	4.55	0.037
Studentype(Treatment)	2	17.72	17.72	8.86	0.19	0.830
Error	55	2599.70	2599.70	47.27		
Total	58	2828.41				

Figure 5.30: Group performance comparison wrt VSM using General linear model (GLM)

5.8.2 Evaluating the performance of treatment group(SMED Lab participation) against control group(None participation in SMED lab

In this analysis the performance of all three groups was done to determine if the treatment group (Participation) in SMED hands-on lab translated to better conceptual understanding. It was hypothesized that participation of hands-on lab leads to a better conceptual understanding, and if this was the case it was expected that the group participating in the SMED hands-on lab would score significantly better than the none participating groups. Two out of 6 groups participated in a hands-on lab project described earlier in section 5.5.3 on page 152. All groups participated in class every single minute of exchange lecture. After the conclusion of this lecture and lab project, an in-class written test was given to establish student comprehension of the SMED concept. A total of seven questions composed of a combination of multiple choice and fill in the blank type questions. The questions used to assess students conceptual understanding are provided in the appendix F.2. Figure 5.32 shows the aggregated scores with respect to each SMED test question.

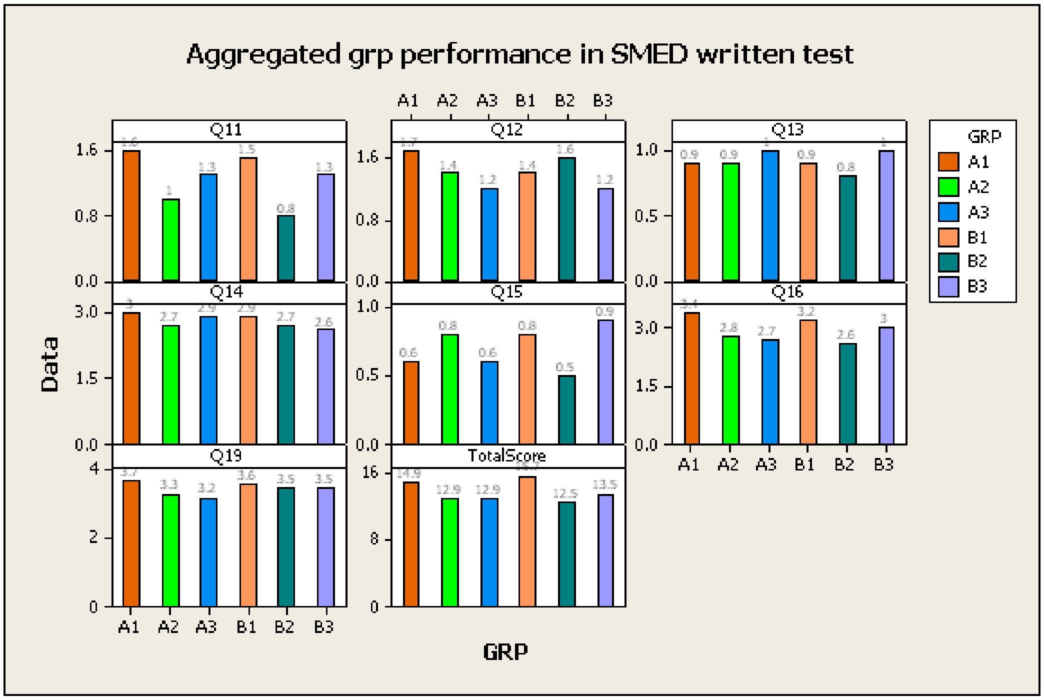


Figure 5.31: Group performance Comparison with respect to SMED test questions

Groups A1 and B1 participated in both the SMED classroom lectures in addition to hands-on SMED project. The performance of each group was assessed through a written test whose scores are summarized in Figure ??. While the total scores for groups A1 and A2 appear to be relatively larger, the same cannot be said with respect to all individual questions. From Figure ??, it is apparent that both Groups A1 and B1 appeared to perform relatively better for questions Q11, Q16, and Q19.Iin order to reach a conclusion on the significance in the difference in test scores it was necessary that a general linear model (GLM) be applied. A GLM was relevant since the design was unbalanced. A General Linear Model with two factors at 2 levels each was used for the analysis. The first factor (Smedlab) represents lab participation coded as 1 for non participation and 2 for participation. The second factor (student type) represents the level of each student, coded as 1 for undergraduate student and 2 for graduate student. A fixed factor crossed GLM experimental design was thus used to assess the effect of lab participation on test scores.

Analysis of Variance wrt SMED test questions

Analysis of Variance for Q11, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SMED_Lab	1	1.6062	2.8756	2.8756	7.31	0.009
Studentype(SMED_Lab)	2	1.9305	1.9305	0.9652	2.45	0.095
Error	55	21.6497	21.6497	0.3936		
Total	58	25.1864				

Analysis of Variance for Q19, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SMED_Lab	1	3.0188	4.1465	4.1465	4.20	0.045
Studentype(SMED_Lab)	2	3.3279	3.3279	1.6639	1.69	0.195
Error	55	54.2974	54.2974	0.9872		
Total	58	60.6441				

Analysis of Variance for Tot_SMED, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SMED_Lab	1	36.840	36.560	36.560	10.60	0.002
Studentype(SMED_Lab)	2	4.249	4.249	2.124	0.62	0.544
Error	55	189.657	189.657	3.448		
Total	58	230.746				

Figure 5.32: Significantly

Figure 5.32 shows the results of GLM ANOVA analysis for only those questions that were found to show significant differences between the performance of the treatment group (Grp A1 and B1 that participated in SMED project) and the control group (None participation in SMED project). Out of a total of seven questions assessed Figure **??** shows that questions Q11 and Q19 indicated a significant difference in performance between the groups, with p-values of 0.009 and 0.045 at 95% confidence interval. The p-values obtained for other questions indicated no significant difference in performance between treatment and control. However, a significant difference between the groups was obtained for the total score (Tot_SMED) with a p-value of 0.002. The significant difference in the total score indicates that despite the absence of significant difference on some test questions, the treatment group still performed relatively better on some questions such as to influence the overall performance in favor of the treatment group.

5.8.3 Discussion

Assessing student's assessment is an important aspect for evaluating the effectiveness of intervention strategies in education. In the case of hands-on lab assessment at Auburn University, a treatment control experimental design was used in which the treatment group was subjected to both hands-on learning activities through lab work and classroom lectures. The control group, was only subjected to the lecture. While the performance comparisons for the individual questions did not show any conclusive difference (p-values > 0.05) among the treatment groups and control, the overall performance score for the treatment group indicated significant difference between the control and the treatment groups for the two sets of experiments. In the first experiment that involved assessing the effectiveness of value stream mapping hands-on exercise on students conceptual understanding, an ANOVA analysis indicated that students that participated in the value stream mapping hands-on exercise performed significantly better with respect to the overall score. Comparisons made using at 95% confidence interval yielded a p-value of 0.023 indicating significance difference between the control and treatment group. With respect for the value stream mapping questions, students that participated in this lab had a greater group aggregated score than their counterparts. Comparisons at individual question levels yielded only two questions that showed a significant difference in performance between the groups. The treatment groups appear to have significantly performed better on questions 12 and 18 with p-values of 0.0032 and 0.0023 respectively. It would appear that strong performance on question 18 for the control group can be attributed to similarities with hands-on lab assignment (see section figure 5.3, on page 148) and appendix F.1 . The hands-on experience with value stream mapping appears to have had strong influence on the performance of the control group with respect to question 18. The main difference between question 18 and the rest of question is that it involves the use of an analytical tool rather than relying of student recall of facts. It would thus appear that because the treatment group may have performed better on this question because they used the tool in a practical setting as opposed to their counterparts that were taught about the tool, but may not have been actively putting it to use.

The results of the second experiment in which the treatment group participated in the single minute of exchange of dies (SMED) hands-on lab described in section 5.5.3 showed similar results to the first experiment. Out of a total of seven questions tested, the treatment group (hand-on lab participation) performed better in only 2 questions. However, the treatment group scored significantly better with respect to the overall test score, thus indicating that the treatment group must have performed better on most questions, although not significantly different at the individual questions level as indicated by p-values of less than 0.05. In a similar manner, it was interesting to note that significant differences in performance between the groups was obtained for the analytical type questions (question 18, see appendix F.2), rather than the recall type of questions in which students were required to state the facts related to the material taught in class.

5.8.4 Conclusion

The data used in the study showed statistically significant results for the overall score and in some cases individual questions. The statistical analysis indicates that students' participation in hands-on learning contributes to students' development in the use of specific skills that are subject to the lab. While there there were no statistical significant differences in performance between the control group and treatment group for the majority of questions tested, significant difference were found for questions that required analytical and problem solving skills related to specific tools used that were part of the lab. While students in the control group (non lab group) may have practiced using the tools tested in exam on an individual basis, the success of lab group participants with respect to analytical problems may have attributed to a number of factors that include the benefits of collaborations during labs, thus leading to increased learning occurring at the aggregated level. It is possible that weaker students may have benefited more from this collaboration thus raising the aggregated score of the treatment group compared to the control group. The results shows strong evidence that the use of hands-on labs is beneficial to student learning, particularly when attempting to develop specific skill-sets related to the use of industrial engineering tools. The result of students' surveys also indicated that the students who participated in the hands-on labs associated with manufacturing related courses believed that the hands-on labs benefited their learning experience, further reinforcing the truth regarding the hypothesis that hands-on labs add value to students learning.

Chapter 6

Summary, Conclusions, and Future Work

The motivation for this dissertation was to contribute a potential methodology that can be used in manufacturing curriculum to bridge the competency gaps of manufacturing students. This is an important contribution considering the stark projections in the shortfall of competent skilled professionals in the manufacturing sector. The American Society of Engineering Education has previously reported that educational institutions are not in line with the country's increasing demand. Manufacturing as a career option has suffered an image problem as well , with progressively less and less students enrolling in manufacturing related fields with each passing year. The over reliance of the lecture as a predominant method of instruction in technical courses is largely to blame for decreased interest and understanding of what manufacturing entails. The image of manufacturing as a potential career path needs to be resuscitated.

In this dissertation we established the important elements necessary for effective manufacturing education by conducting a meta-analysis of existing research relevant to manufacturing education as well as conducting stake-holder surveys. Findings indicate that among the many elements that are part of manufacturing education, a subset of these lend themselves well to hands-on instruction and thus the importance of integrating them as part of hands-on learning activities in an effective manufacturing curricula. Survey results indicated that industry considered problem solving skills, teamwork, and written and communication skills as the attributes most desired among many others that are the most sought after attributes of future Manufacturing Engineers.

Prioritization of the important elements needed for an effective manufacturing curricula was imperative as it can serve as a guideline for colleges with manufacturing curriculum on what element they should integrate focus on in order to better prepare manufacturing student for careers in manufacturing. Not only is knowing what elements are to include an effective manufacturing curriculum enough, but knowing what level of instruction each of the identified elements should be taught is essential. Survey results indicate that teaching that integrates scaled down equipment and industrial grade equipment as part of hands-on learning is the most beneficial to students. Live simulation that imitates real world manufacturing environments appears to be beneficial for a majority of students surveyed. However it should be acknowledged that it is not always possible to conduct live simulation for some elements of manufacturing education due to any number of possible reasons, such as safety concerns for students, prohibitive cost of equipment and lack of adequate staffing levels among many other possible reasons. As an alternative to live simulations and use of physical hardware, computer simulations should be considered. We have followed this methodology in this dissertation to assess the possible benefits to students learning. A realistic simulated factory (Tiger Motors) was designed to be used as testbed for a number of interdisciplinary manufacturing hands-on activities. Tiger Motors was designed to be mixed model assembly line with the ability to accommodate three models of vehicles. Students were able to work on number of hands-on activities, all of which were driven by one common goal, to improve system performance in a similar manner to what you would find in real industry. To assess the effectiveness of hands-on labs on students learning, students surveys were conducted to gather students' perceptions on the value of the introduced hands-on activities. In addition, a post test experimental design in which the performance of a control group was assessed against that of treatment group. Results of both the students' surveys and students' performance on written test indicate that not only do hands-on labs increase students interest level in the subject matter, but benefits student learning with respect to specific skill sets that are considered vital competencies in many manufacturing careers.

6.0.5 Future Research

The findings of this dissertation support the hypothesis that hands-on learning can be beneficial to students' learning. While the research goals were met, a number of potential areas for further research were identified. The two years experience of working with students in the lab revealed a number of potential research opportunities. Student collaborations are an important part of student learning. While students in most hands-on labs are normally randomly assigned to groups, there is a need to investigate the impact of team dynamics on students learning. In a number of labs associated with the findings of this research, students were often required to work in groups as large as ten. A team leader was normally assigned by group consensus and other team roles were decided among the members of the group. It was apparent that the success of each group, in many cases depended on the organizational skills of the team leader assigned as well as the ability of the group to work well as a unit. The groups that appeared to have good leadership seemed to to be more successful, with team members reporting satisfaction with work done in the group. However, this was not the case for the groups that lacked good communication, which led to disharmony among team members and confusion on the role of each team member. Observing these different team dynamics was interesting, taking into account the alleged competency gaps. The industry survey indicated that team work and communication are highly sought competencies in manufacturing.

An investigation on how team composition affects overall team performance, as well as impacts students' learning in a group setting, may be an important research area that can help us learn how to form successful collaborative teams based on team member's learning styles and abilities. Establishing students' learning styles using any of the the proven pedagogical learning theories, such as Kolb's learning theory or Blooms taxonomy, could be used as a basis for grouping students in ways that benefit all team members.

The lab needs to be interdisciplinary in nature, providing an opportunity of testing various theories covered in manufacturing related courses. The lab should provide students with the platform to put into practice other tools taught in different classes. It is always helpful for students to see real application of particular tools where tangible results can be observed. Taking into consideration that a large number of students that participated in the lab had previously taken courses in linear programming, quality control, and ergonomics classes as part of their degree requirements, the opportunity of participating in a manufacturing lab was an opportunity to apply put some of the theories and concepts taught in those courses into practice. The lab provides a realistic platform for students to apply some of the tools taught in the respective courses. A good example would be the application of human factors design principle in evaluating workstation design. This aspect could be incorporated as one of the required lab elements for a fuller interdisciplinary learning. Incorporating human factors would be helpful in reducing the number of errors associated with assembly tasks due to inadequately designed work instruction and poorly laid out work stations. Such skills are important for manufacturing engineers.

Making use of an interdisciplinary group according to prior classes taken could be helpful in forming effective teams that will benefit all team members.

A number of quality related issues were apparent in many of the live simulation runs conducted in the lab. While the students did their best to eliminate the occurrence of errors in successive runs, there wasn't much consideration for the use of any quality control tools or any scientific quality methods for reducing the number of defects occurring in the the system. Design for assembly and manufacturability was another potentially important lab element that needed to be considered in future labs, especially in assembly operations. Integrating design for manufacturing and assembly guidelines in these labs could be useful in helping students get a firm gripper of the concepts. The failure to take into consideration these design guidelines was apparent in various assembly configurations reached by various student groups.

An interdisciplinary lab like Tiger Motors may be the opportunity for faculty members responsible for the teaching of various courses to develop hands-on modules that could be used as typical teaching references for in-class discussion. For instance, the lab would provide a good reference for simulation classes. Historical production data has been collected over the two year period that Tiger Motors lab has been in existence. While in many cases, students in the simulation class are required to undertake simulation projects, Tiger motors provides a test bed for students wishing to test the simulation skills using Data that can be verified and validated. Data related to production runs collected over a period of a year the lab has been operating, can be useful to students taking the simulation class. The sentiment has already been echoed by some distance learning students that suggested that, the existence of a simulation model of the production runs could be a good add on especially for outreach students.

The lab also provides a platform for testing out newer advanced technologies that may be an integral aspect for 21st century new age manufacturing. The use of radio frequency identification technology is slowly gaining popularity in manufacturing and many other fields. There is need for students to have a conceptual understanding of how it works so as to equip students with the ability of prescribing solutions that utilize new age technology. The material replenishment at Tiger Motors utilizes physical kanban cards which could be substituted with a computerized kanban system that utilizes RFID.

Another opportunity lies in use of information technology. It is envisaged the 21st manufacturing will be paperless. The use of video based work instructions as well real time data collection and reporting are some challenges faced by future engineers. In simulated production runs most of data was collected manually using forms provided in the appendix. This process proved too tedious and error prone. The lab provides an opportunity for students to work on individual group projects to make the improvements just outlined.

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Appendices

Appendix A

An Industry perspective on important elements required for manufacturing education

A.1 Student perceptions on introductory manufacturing lab in enhancing student learning and interest

Default Question Block

Informed Consent Form

Introduction
This Survey **seeks industrialist's perspective on what elements/components should be included in an effective manufacturing teaching laboratory** designed with the purpose of bridging the competency gap of graduating manufacturing students. This study is being conducted by Yamkelani Moyo, PhD candidate in the Industrial and Systems under the Direction of Dr Richard Sesek, Assistant Professor in the Industrial and Systems Engineering Department at Auburn University. We hope to use the information you provide as input in the development of an effective taxonomy for manufacturing education.

Procedures
You will be asked to answer a series of questions based on your own experience as a **direct/indirect employee** or **employer** in the manufacturing industry. It should not take more than 20 minutes to complete this survey . Questions are designed to determine what elements/componets you would expect an effective manufacturing curriculum designed with the goal of bridging the competency gaps in manufacturing to have**.** Your views regarding on how manufacturing students should be trained at University level to improve their employability skills is important. This questionnaire is being conducted using Qualtrics online survey software.

Risks/Discomforts
Risks are minimal for involvement in this study. Although we do not expect any harm to come upon any participants due to electronic malfunction of the computer, it is possible though extremely rare and uncommon.

Benefits
There are no direct benefits for participants. However, it is hoped that through your participation, researchers/educators will gain valuable knowledge on how to streamline manufacturing curriculum to fit the dynamic nature of today's manufacturing industry. The results of this survey together with perspectives of educators will provide valuable information required to develop an effective taxonomy for manufacturing education. This taxonomy could thus serve as basis for developing consensus guidelines for an effective manufacturing curriculum required to revamp the US manufacturing industry.

Confidentiality
All data obtained from participants will be kept confidential and will only be reported in an aggregate format (by reporting only combined results and never reporting individual ones). All questionnaires will be concealed, and no one other than then primary investigator and assistant researches listed below will have access to them. The data collected will be stored in the HIPPA-compliant, Qualtrics-secure database until it has been deleted by the primary investigator.

Compensation
There is no direct compensation, rather than the satisfaction one may get for making a contribution intended to revamp the manufacturing education and thus indirectly contribute towards revitalizing the manufacturing sector.

Participation
Participation in this research study is completely voluntary. You have the right to withdraw at anytime or refuse to participate entirely. If you desire to withdraw, please close your Internet browser and notify the principal investigator at this email: yzm 0005@auburn.edu.

Questions about the Research
If you have questions and you do not feel comfortable asking the researcher, you may contact Auburn Universities University Office of Human Subjects Research or Institutional Review by phone (334)-844-5966 or email at hsubjec@auburn.edu or IRBChiar@auburn.edu. s

I have read, understood, and printed a copy of the above consent form and desire on my own free will to participate in this study.

- Yes
- No

What position do you hold in your Company?

- Executive
- Upper Management e.g. Production Manager, Plant Manager, Quality Assurance
- Professional e.g. Quality Engineer, Safety Engineer, Mechanical Engineer
- Technician e.g. Drafters, PLC programmer,
- Other

What is the highest level of education you've attained

- PhD
- Masters
- Bachelors
- Associate
- High School

Are you an Engineering Degree holder

- Yes
- No

What type of Engineering degree did you study for

- Industrial Engineering
- Manufacturing engineering
- Electrical engineering
- Chemical Engineering
- Safety Engineering
- Other

Select from the list given below, the category that best describes the manufacturing activities of your organization:

- Fabricated Metal Products, e.g. Automobiles, Air craft, machine building
- Metal processing. e.g. Steel, aluminum etc
- Ceramics and none metal processing
- Chemicals, Coal, petroleum, plastics and rubber, pharmaceuticals
- Paper, paper products, printing, publishing
- Wood and wood products
- Other manufactured products

What is the number of full time employees directly employed in your organization?

- Less than 50
- Between 50 and 100
- Between 100 and 200
- Between 200 and 1000
- More than 1000

What type of Manufacturing would you consider your company to be engaged in:
Low variety manufacturing firms produce a select number of products over a number of years before switching to a different product.

- High Volume, Low variety manufacturing activities
- Low Volume, High Variety manufacturing activities
- Low Volume, Low Variety
- High volume, High variety

Competency Gaps in Manufacturing:

Taking into perspective your own experience as an entry level professional and any interactions you may have had with other entry level professionals in manufacturing related jobs, please indicate your agreement with the following statement:

Introducing hands-on approach to teaching the the given topics in a manufacturing curriculum at college level would be beneficial in addressing the competency gap in manufacturing.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree

Written and Oral Communication	◯	◯	◯	◯	◯
Specific manufacturing process Knowledge	◯	◯	◯	◯	◯
Manufacturing process Control	◯	◯	◯	◯	◯
Product and Process Design	◯	◯	◯	◯	◯
Business knowledge/Skills	◯	◯	◯	◯	◯
Project Management	◯	◯	◯	◯	◯
Teamwork/ work effectively with others	◯	◯	◯	◯	◯
International perspectives	◯	◯	◯	◯	◯
Manufacturing Systems knowledge	◯	◯	◯	◯	◯
Quality Systems knowledge	◯	◯	◯	◯	◯
Materials knowledge	◯	◯	◯	◯	◯
Problem solving skills	◯	◯	◯	◯	◯
Supply Chain Management	◯	◯	◯	◯	◯

Entry Level Competence

Using a scale of 1 to 10, with 1 for least competent and 10 most competent, Indicate your perspective on the competency of newly graduated manufacturing/Industrial engineers with regards to competency and effectiveness in the manufacturing environment.

	0	1	2	3	4	5	6	7	8	9	10
Competency											

Competency Gaps in Manufacturing:

Rank the the given competency gaps according to how important they are. Importance in this sense implies that addressing the said competency gap through changes in manufacturing curriculum will benefit manufacturing industry.

	Least Important: 1	2	3	4	Most Important 5
Business knowledge and skills	◯	◯	◯	◯	◯
Project Management	◯	◯	◯	◯	◯
Lean Manufacturing and Six	◯	◯	◯	◯	◯

Sigma knowledge					
Environment, occupational health and Safety	○	○	○	○	○
knowledge and competency in production machinery operations	○	○	○	○	○
Supply chain management	○	○	○	○	○
Knowledge raw materials	○	○	○	○	○
Manufacturing process control	○	○	○	○	○
Written and and Oral Communication Skills	○	○	○	○	○
Product and Process Design	○	○	○	○	○
Quality Systems knowledge	○	○	○	○	○
Specific Manufacturing process knowledge	○	○	○	○	○
Technical drawing	○	○	○	○	○

Manufacturing Control:

Following the example shown below, please fill out the table below to best describe your belief and views on what elements of manufacturing control need to be included in manufacturing education to address the competency gap that may exist in this category:

Key to teaching Levels:

0. Not required
1. Conceptual (Theory, Mathematical Models)
2. Computer Simulation and Gaming
3. Physical Simulation Modeling and Games (e.g. Using Lean simulation games e.g. Lego factory)
4. Table top (Scaled down equipment)-(e.g. table top manufacturing processes equipment)
5. Industrial Grade Equipment/Commercial Software

Example:

Using the Key to teaching levels shown above, complete the table as shown below if your believe that:

- Process Monitoring should be an **Optional** topic in manufacturing curriculum that needs to be taught with the aid of **Computer Simulation** (**2**)
- Process Control is **Useful** and needs to be taught using **industrial Grade Equipment (5)**.

	Necessary	Useful	Optional	Not needed
Process Monitoring (Statistical process control, real time process monitoring)			2	
Process control		5		

Complete the Table Given below following the Example above:

	Necessary	Useful	Optional	Not needed
Process Monitoring (Statistical process control, real time process monitoring)				
Process control				

Shop floor control				
Computer Aided Inspection				
Maintenance Management				

Product Design:
Product design is the process of creating a new product to be sold by a business or enterprise to its customers. it is concerned with efficient and effective generation and development of ideas through a process that leads to new products. Product designers conceptualize and evaluate ideas, making them tangible through a systematic approach. their role is to combine science, art and technology to create three dimensional goods. This evolving role has been facilitated by digital tools that allow designers to communicate, visualize and analyze ideas in a way that would have taken greater resource in the past.

How important is it for Manufacturing/Industrial Engineers to acquire knowledge in Product Design through manufacturing education:

- Extremely Important
- Very Important
- Neither Important nor Unimportant
- Very Unimportant
- Not at all Important

Product Design:
Following the example given below, complete the table to best describe your view on what elements of product design need to be included in the manufacturing curriculum to address the manufacturing competency gap?

Key to teaching Levels:

0. Not required
1. Conceptual (Theory, Mathematical Models)
2. Computer Simulation and Gaming
3. Physical Simulation Modeling and Games (e.g. Using Lego to demonstrate concepts in Lean and Six Sigma)
4. Table top (Scaled down equipment)-(e.g. table top manufacturing processes equipment)
5. Industrial Grade Equipment/Commercial Software

Example:

Using the Key to teaching levels above, complete the table as shown below if you believe that:

- Computer aided Design/Drafting is **necessary** topic in manufacturing curriculum that needs to be taught with **industrial grade equipment** (**5**).
- Computer aided engineering is **Useful** and needs to be taught using **Industrial Grade Equipment (5)**.

	Necessary	Useful	Optional	Not Needed
Computer Aided Design/Drafting	5			
Computer Aided Engineering		5		

Complete the Table Given below following the Example Given above:

	Necessary	Useful	Optional	Not Needed
Computer Aided Design/Drafting				
Computer Aided Engineering				
Process Design				
Facility Design/Plant layout				
Design for Manufacture/Design for Assembly				
Group Technology				
Any other important component				

Product Design:

Indicate your views regarding the capability of manufacturing engineers with regards to their competency in the use of any of the following product or process design tools:

- Design specification generation
- 2 dimensional modeling tools: eg. Auto cad, Auto-desk inventor
- 3 dimensional modeling tools: e.g. Solid works, Auto-cad, Catia, Solid Edge
- Rapid Prototyping
- Value Engineering
- Design for Manufacture/Design for Assembly

	Design Specification generation	2 D Modeling Software	3 D Modeling Software	Value Engineering	Design for Manufacture (DFM)/Design for Assembly (DFA)
Should be able to Use	○	○	○	○	○
Should have basic knowledgeable and have ability to interpret	○	○	○	○	○
Not necessary	○	○	○	○	○
Does not Apply	○	○	○	○	○

Manufacturing process Automation and technologies:

Following the example shown below, please complete the table to best describe your view on what elements of manufacturing automation and technologies need to be part of manufacturing education to address the competency gap in manufacturing.

Key to teaching Levels:

0. Not required
1. Conceptual (Theory, Mathematical Models)
2. Computer Simulation and Gaming
3. Physical Simulation Modeling and Games (e.g. Using Lego to demonstrate concepts in Lean and Six Sigma)
4. Table top (Scaled down equipment)-(e.g. table top manufacturing processes equipment)

5. Industrial Grade Equipment/Commercial Software

Example:

Using the Key to teaching levels above, complete the table as shown below if you believe that:

- Automated material handling is **necessary topic** in manufacturing educations that needs to be taught with **industrial grade equipment (5)**.
- Automated packaging is useful and can be taught using physical **simulation models (3)**.

	Necessary	Useful	Optional	Not Needed
Automated Material Handling	5			
Automated Packaging		3		

Complete the Table Given below following the Example Given above:

	Necessary	Useful	Optional	Not Needed
Automated Material Handling				
Automated Packaging				
Automated Storage and Retrieval Systems				
Numerical Control				
Computer Numerical Control				
Programmable logic Controllers				
Direct/Distributed Numerical Control				
Adaptive Control				
Flexible Manufacturing Cells				
Machine Vision				
Radio Frequency identification applications (RFID)				
Metrology Using Automated Inspection Methods				

Business Function in manufacturing eduction

How important is it for Manufacturing/Industrial Engineers to acquire knowledge and skills related to business side of manufacturing

- Not at all Important
- Very Unimportant
- Neither Important nor Unimportant
- Very Important
- Extremely Important

Business Functions in Manufacturing:
A list of elements that are potential components of a manufacturing curriculum are provided. From this list of elements provide your view to indicate whether any of these elements should be made an integral part of manufacturing education curriculum to close the competency gap that exist in manufacturing.

Following the example given below please complete the table below to best describe your beliefs and views on what Business function elements should be made and integral part of manufacturing education?

Key to teaching Levels:

0. Not required
1. Conceptual (Theory, Mathematical Models)
2. Computer Simulation and Gaming
3. Physical Simulation Modeling and Games (e.g. Using Lego to demonstrate concepts in Lean and Six Sigma)
4. Table top (Scaled down equipment)-(e.g. table top manufacturing processes equipment)
5. Industrial Grade Equipment/Commercial Software

Example:
Using the Key to teaching levels above, complete the table as shown below if you believe that:

- Demand forecasting is a **necessary** topic in manufacturing education that need to be taught using **Industrial grade equipment or software (5)**
- Order entry should be made an **optional** component of manufacturing curriculum and teaching it at the **conceptual/theoretical (1)** level should be the minimum teaching requirement.

	Necessary	Useful	Optional	Not Needed
Demand Forecasting				0
Order Entry			1	

Complete the Table Given below following the Example Given above:

	Necessary	Useful	Optional	Not Needed
Demand Forecasting				
Order Entry				
Customer Billing				
Payroll				
Accounting				

Manufacturing Planning:
Manufacturing Planning encompasses all planned activities involved in determining the most efficient way of producing a product. It requires planning both manpower and machinery.

Following the example given below, please complete the table to best describe your view on what elements of manufacturing planning need to be made an integral part of manufacturing education curriculum to address the competency gap that exist in manufacturing education.

Key to teaching Levels:

0. =Not required
1. =Conceptual (Theory, Mathematical Models)
2.= Computer Simulation and Gaming
3. =Physical Simulation Modeling and Games (e.g. Using Lego to demonstrate concepts in Lean and Six Sigma)
4. =Table top (Scaled down equipment)-(e.g. table top manufacturing processes equipment)
5.= Industrial Grade Equipment/Commercial Software

Example:

Using the Key to teaching levels above, complete the table as shown below if you believe that:

- Material Requirements planning (MRP) is **necessary** topic in manufacturing curriculum that needs to be taught with **industrial grade equipment** (**5**).
- Capacity Requirements planning is **Useful** and can be taught using **Computer Simulation and Gaming (2)**.

	Necessary	Useful	Optional	Not Needed
Materials Requirement planning (MRP)	5			
Capacity requirements planning (CRP)		3		

Complete the Table Given below following the Example Given above:

	Necessary	Useful	Optional	Not Needed
Materials Requirement planning (MRP)				
Capacity requirements planning (CRP)				
Computer aided process planning (CAD)				
Established standard Time Data (Stop time studies and Predetermined time studies)				
Scheduling				
Assembly line Balancing				
Bill of Material Processor				
Cost Estimating				

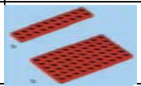
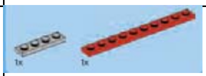
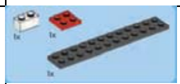
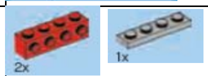
Appendix B

Unbalanced work instructions

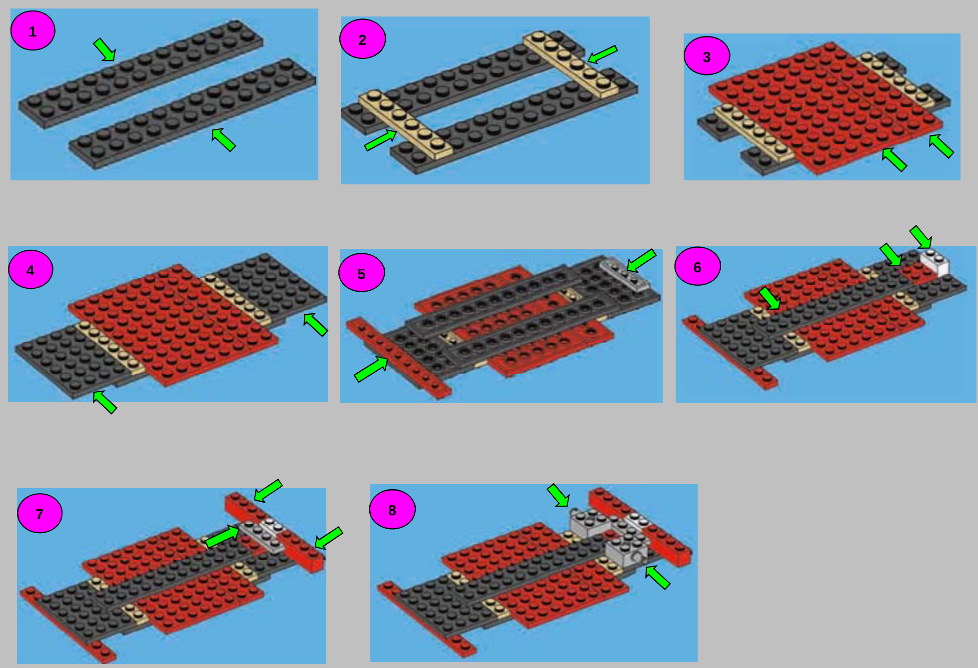
Operations work standard sheet

R & D	PROD

Process: TL Setup **ST 1 ASSY** **AU P/N: All AU Parts**

Seq No	Operation Element	Part #	Serial #	Key point	T1	T2	T3	T4	T5	Ave
1		-73	-244526							#DIV/0!
2		-54	-4124067							#DIV/0!
3		-40 -41	-383221 -4506961							#DIV/0!
4		-71	-303226							#DIV/0!
5		-85 -38	-4211445 -447721	◆						#DIV/0!
6		-2 -34 -73	-300401 -302221 -244526							#DIV/0!
7		-16 -85	-4157223 -4211445							#DIV/0!
8		-82	-4211529							#DIV/0!

Standard Time(s)

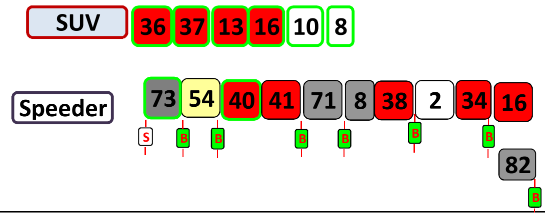


Station Cycle time #DIV/0!

REMARKS

◆ Quality

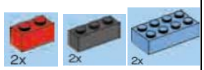
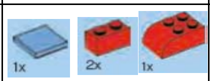
Safety



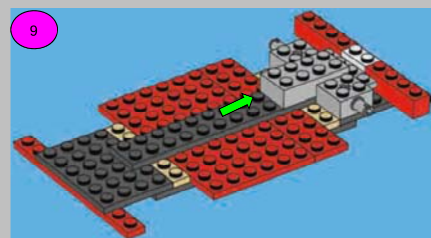
Operations work standard sheet

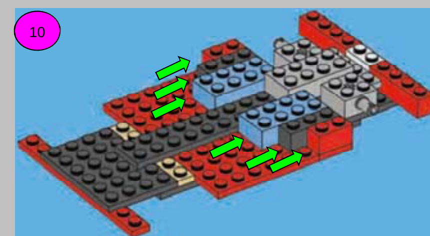
R & D	PROD

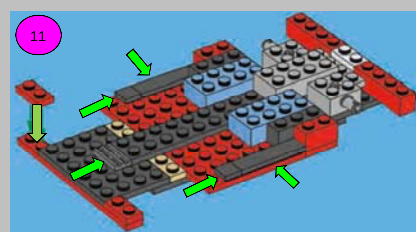
Process: TL Setup ST 2 ASSY AU P/N: All Dow Parts

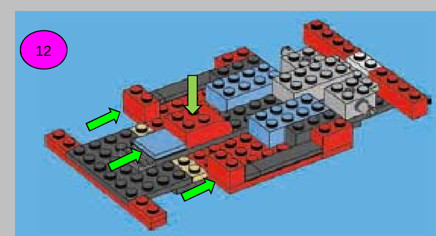
Seq No	Operation Element	Part #	Serial #	Key point	T1	T2	T3	T4	T5	Ave
9		-83	-4211385							#DIV/0!
10		-13 -56 -50	-300421 -362226 -4205058							#DIV/0!
11		-91 -30 -64 -65	-4210631 -302321 -307026 -243126							#DIV/0!
12		-51 -13 -17	-4528357 -300421 -621521							#DIV/0!

Standard Time(s)









REMARKS

Quality

Safety

SUV 7 68 43 44 23 4 94

Speeder 83 13 56 50 91 30 64 65 51 13 17

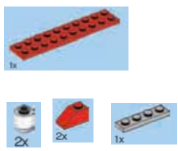
S B B B

Station Cycle time #DIV/0!

Operations work standard sheet

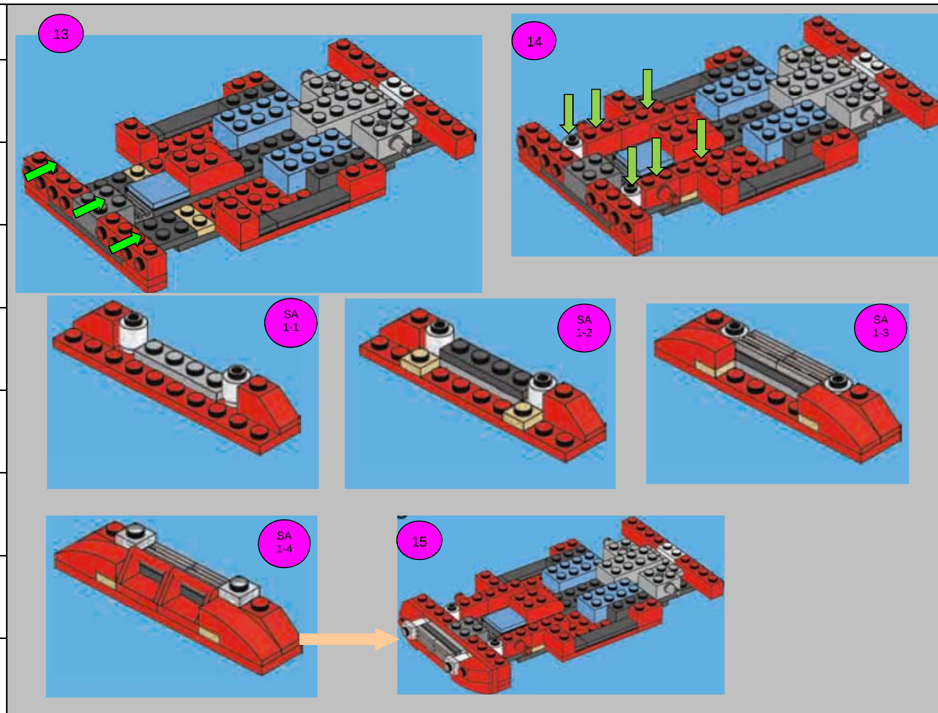
R & D	PROD

Process: TL Setup **ST 3 ASSY** **AU P/N: All AU Parts**

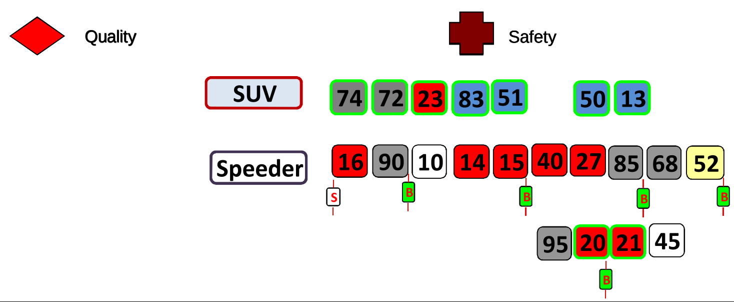
Seq No	Operation Element	Part #	Serial #	Key point	T1	T2	T3	T4	T5	Ave
13		-16 -90	-4157223 -4211060							#DIV/0!
14		-10 -14 -15	-306201 -245821 -362221							#DIV/0!
SA 1-1		-40 -10 -27 -85	-383221 -306201 -4121934 -4211445							#DIV/0!
SA 1-2		-68 -52	-371026 -4159553							#DIV/0!
SA 1-3		-95 -20	-4249040 -4251162							#DIV/0!
SA 1-4		-21 -45	-243221 -3000840							#DIV/0!
15			-front bumper							#DIV/0!

Standard Time(s)

Station Cycle time: #DIV/0!



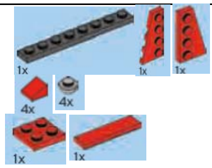
REMARKS

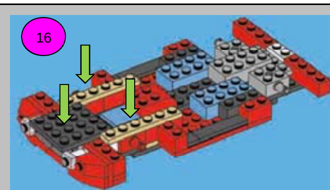


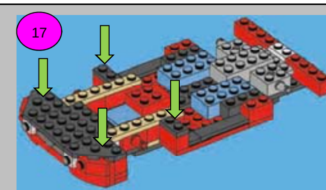
Operations work standard sheet

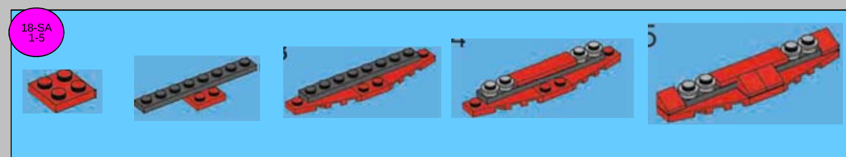
R & D	PROD

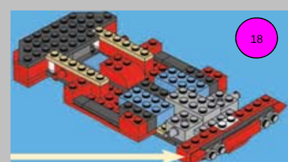
Process: TL Setup ST 4 ASSY AU P/N: All AU Parts

Seq No	Operation Element	Part #	Serial #	Key point	Standard Time(s) T1	T2	T3	T4	T5	Ave
16		-56 -70	-4124067 -4243819							#DIV/0!
17		-59 -63	-302326 -4227684							#DIV/0!
18-SA 1-5		-69 -43 -44 -26 -89 -34 -23	-346026 -4161329 -4160866 -4504379 -4211525 -302221 -243121							#DIV/0!
18			-rear-bumper							#DIV/0!









REMARKS

Quality

Safety

Station Cycle time #DIV/0!

SUV 85 54 28 14

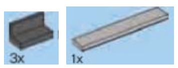
Speeder 54 70 59 63 69 43 44 26 89 34

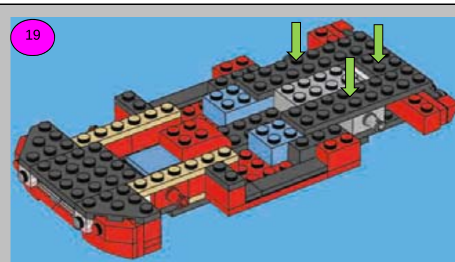
S B B 23 B

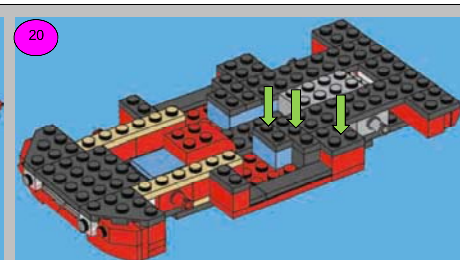
Operations work standard sheet

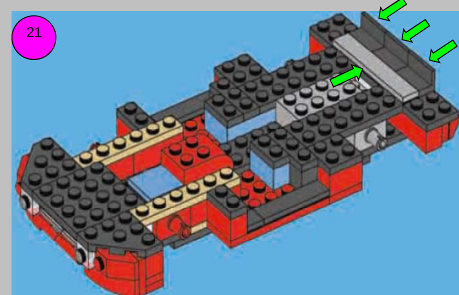
R & D	PROD

Process: TL Setup ST 5 ASSY **AU P/N:** All AU Parts

Seq No	Operation Element	Part #	Serial #	Key point	Standard Time(s) T1	T2	T3	T4	T5	Ave
19		-74 -72	-302226 -303426							#DIV/0!
20		-59 -67 -74	-302326 -362326 -302226							#DIV/0!
21		-81 -84	-486526 -4211549							#DIV/0!
										#DIV/0!







REMARKS

Quality

Safety

SUV: 69, 94; 13, 12, 26, 16, 83, 36, 8, 24

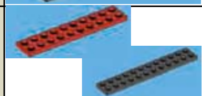
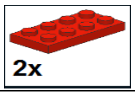
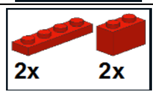
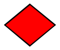
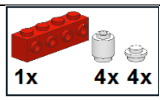
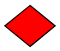
Speeder: 74, 72, 59, 67, 81, 84; S, B, B, B, B

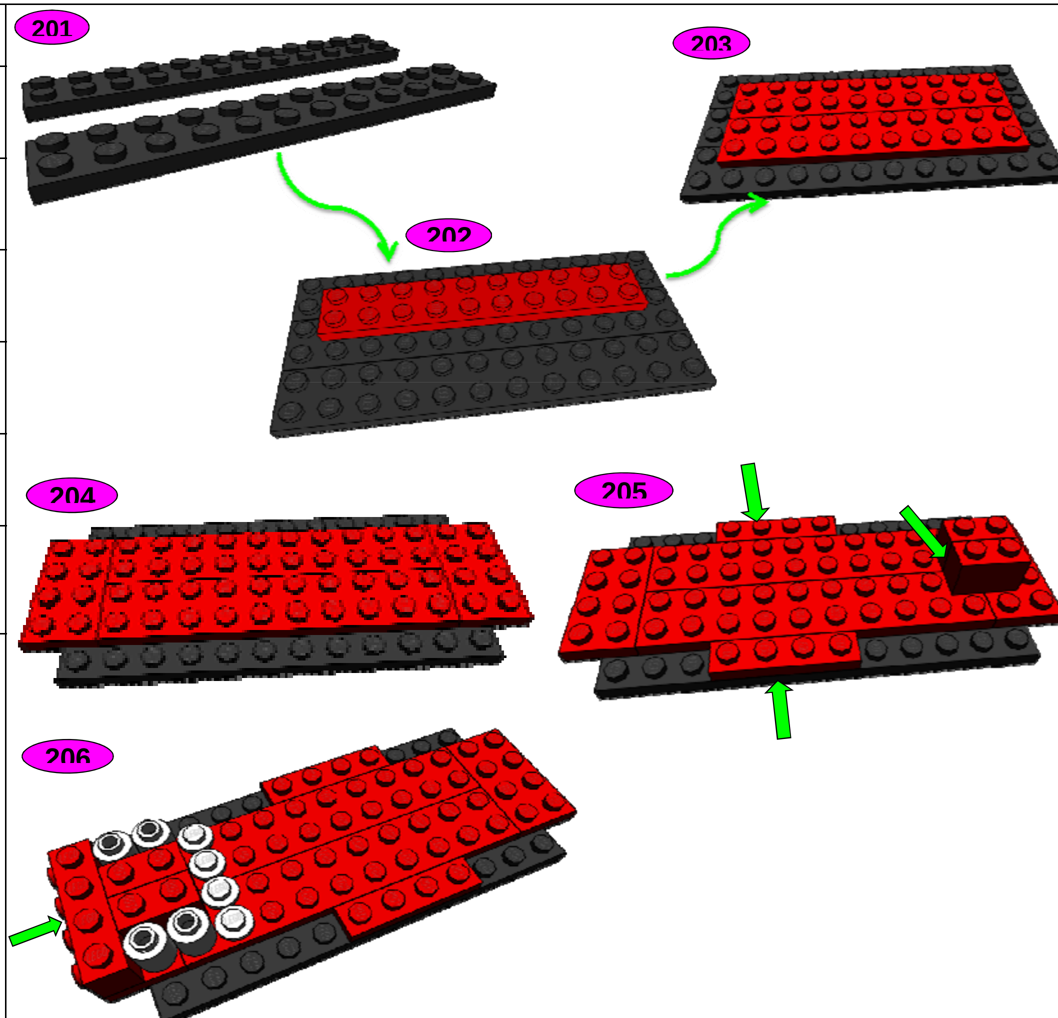
Station Cycle time #DIV/0!

Operations work standard sheet

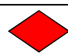
R & D	PROD

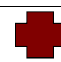
Process: TL Setup **ST 1 ASSY** **AU P/N: All AU Parts**

Op No	Operation Element	Part #	Qty	Serial #	Key point	Standard Time(s) T1	T2	T3	T4	T5	Ave
201		73	2	24526							
202		40 73	1 1	24526 383221							
203		40	1	383221							
204		36	2	302021							
205		37 13	2 2	371021 300421							
206		16 10 89	1 4 4	4157223 306201 421525							



REMARKS

 Quality

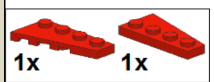
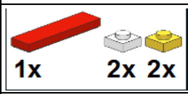
 Safety

36 37 13 10 89
73 54 40 41 71 85 38 2 34
16 82 65

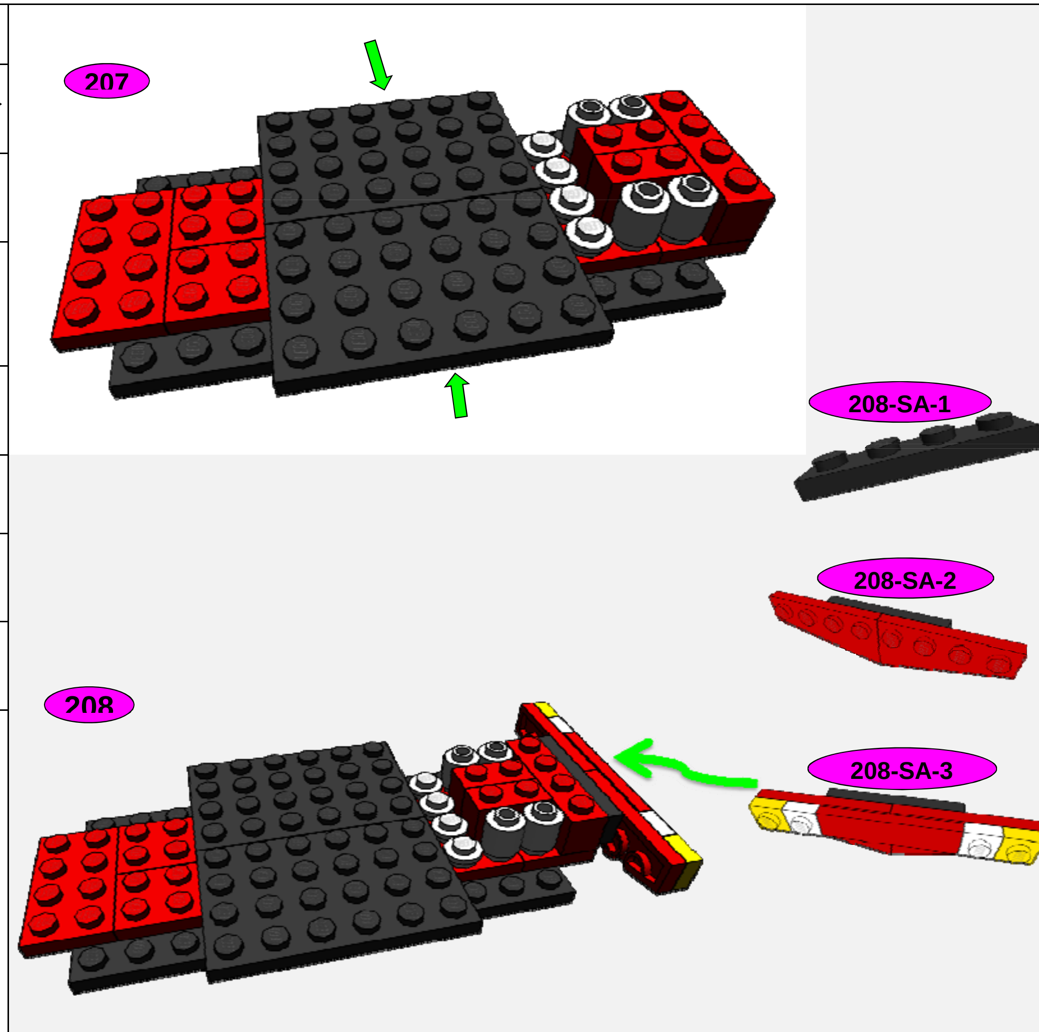
Operations work standard sheet

R & D	PROD

Process: TL Setup ST 2 ASSY AU P/N: All Dow Parts

Seq No	Operation Element	Part #	Qty	Serial #	Key point	T1	T2	T3	T4	T5	Ave
207		71	2	303226	◆						
208-SA-1		68	1	371026							
208-SA-2	 1x 1x	43 44	1 1	4161329 4160866	◆						
208-SA-3	 1x 2x 2x	23 45 94	1 2 2	243121 3000840 4542673							

Standard Time(s)



REMARKS

◆ Quality

✚ Safety

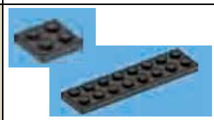
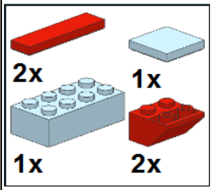
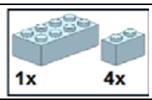
71 68 43 44 23 45 94

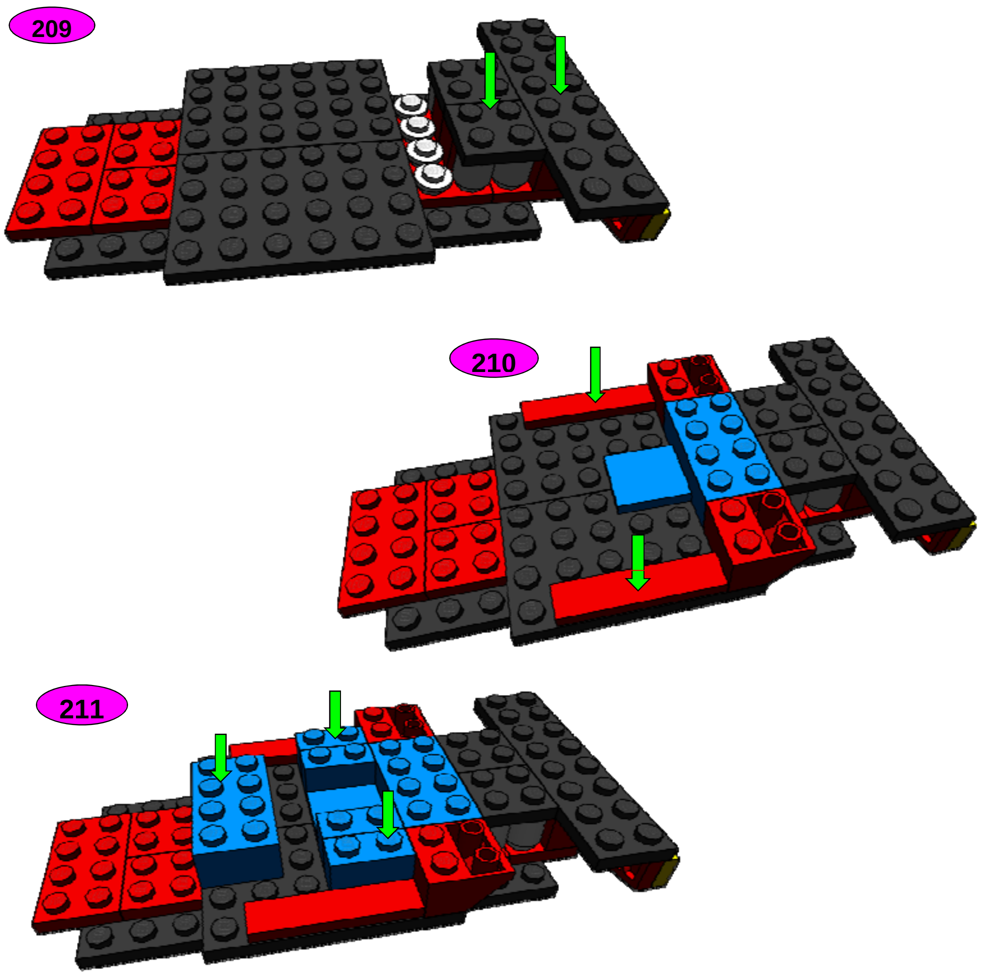
83 13 56 50 91 30 64 65 51 17

Operations work standard sheet

R & D	PROD

Process: TL Setup **ST 3 ASSY** **AU P/N: All AU Parts**

Seq No	Operation Element	Part #	Qty	Serial #	Key point	T1	T2	T3	T4	T5	Ave
						Standard Time(s)					
209		74 72	2 1	302226 303426							
210		23 50 51 28	2 1 1 2	243121 4205058 4528357 366021							
211		50 49	1 4	4205058 4179833							



REMARKS

Quality

Safety

74 72 23 50 51 28 49

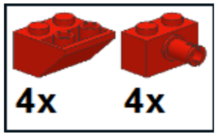
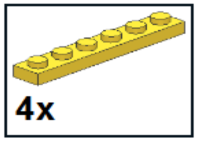
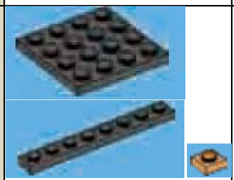
16 90 10 14 15 40 27 85 68 52

95 20 21 45

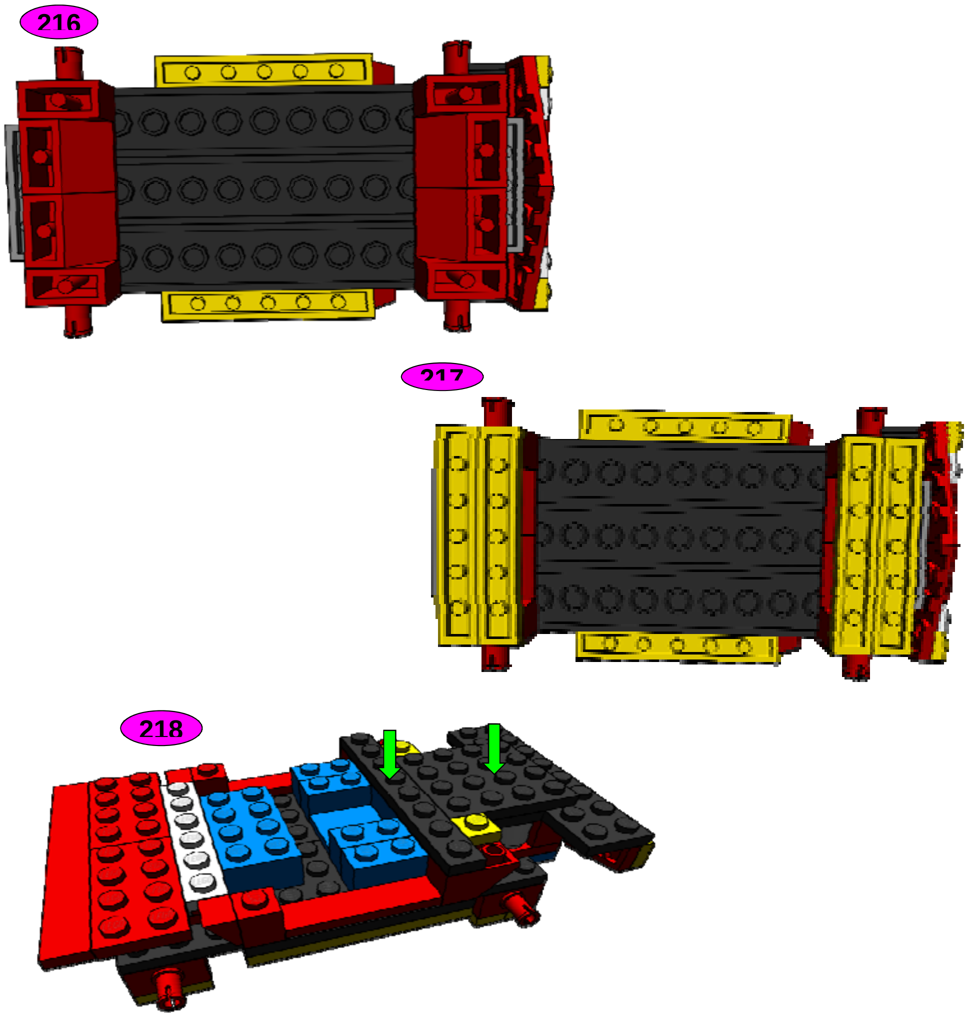
Operations work standard sheet

R & D	PROD

Process: TL Setup ST 4 ASSY AU P/N: All AU Parts

Seq No	Operation Element	Part #	Qty	Serial #	Key point	T1	T2	T3	T4	T5	Ave
216		28 14	4 4	366021 245821							
217		54	1	4124067							
218		70 69 52	1 1 2	4243819 346026 4159553							

Standard Time(s)



REMARKS

Quality

Safety

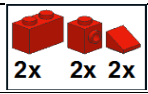
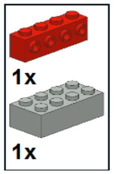
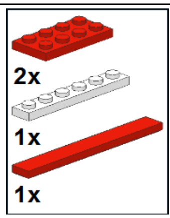
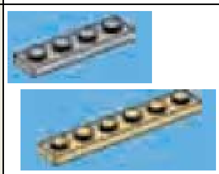
28 14 54 70 69 52

74 72 59 67 81 84

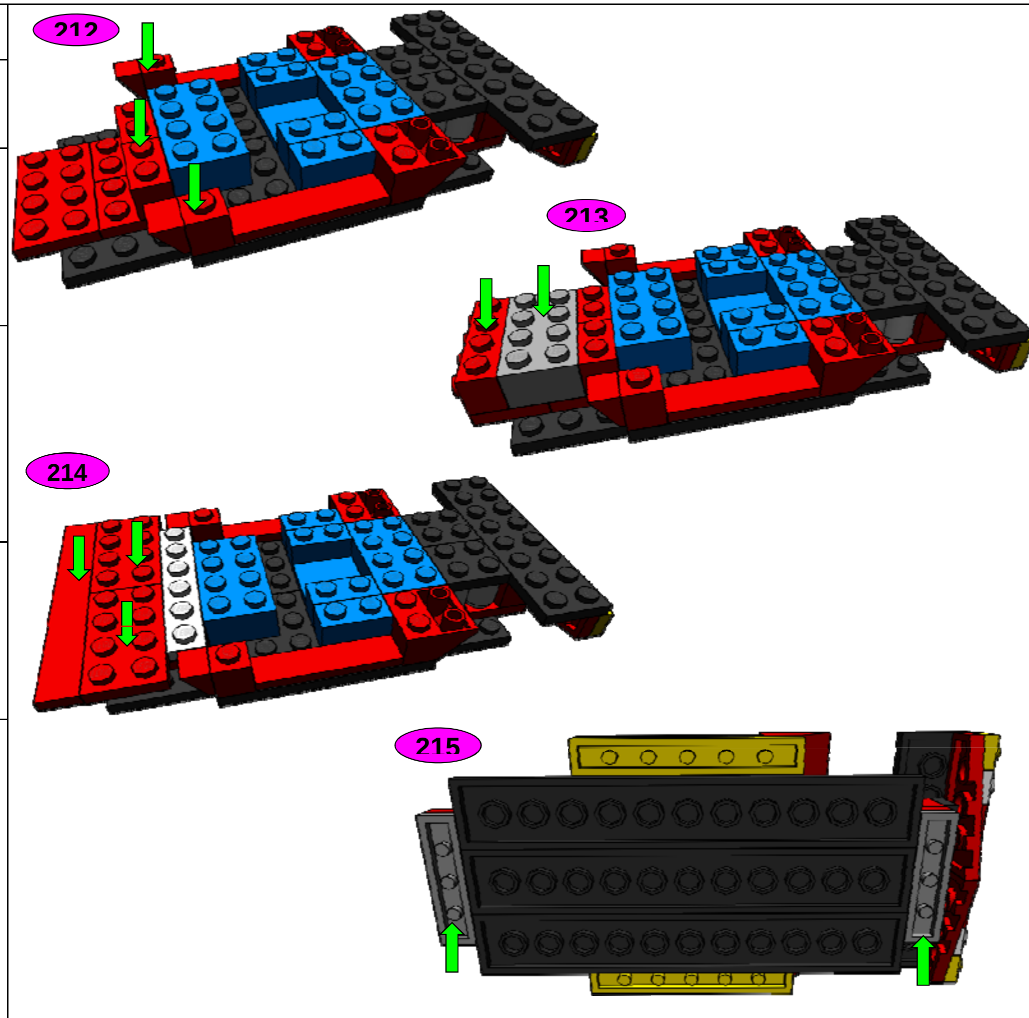
Operations work standard sheet

R & D	PROD

Process: TL Setup ST 5 ASSY AU P/N: All AU Parts

Seq No	Operation Element	Part #	Qty	Serial #	Key point	T1	T2	T3	T4	T5	Ave
212		13 12 26	2 2 2	300421 4558886 4504379	◆						
213		16 83	1 1	4157223 4211385							
214		36 8 24	2 1 1	302121 366601 416221							
215		85 54	2 2	4211445 4124067							

Standard Time(s)



REMARKS

◆ Quality

Safety

13 12 26 16 83 36 8 24 85

54 70 59 63 69 43 44 26 89 34 23

Appendix C

Data Collection forms

Team Roles

Manager

Team Leaders	Designated Area /Responsibility

Station Operators

Station Number	Operator Assigned	
	Operator 1	Operator 2

Material Handler

Quality Controller

Department:	Station:	Study No: Sheet No:
Model: Operation: Plant/Machine: Tools and Guages:		Time off: Time on: Elapsed Time:
		Operative: Clock Number:
Product/Part: DWG No: Quality:		Studied by: Date:
		Checked by:

El. No.	El Description	Observed time										Total OT	Ave-rage OT	R	BT	NT
		1	2	3	4	5	6	7	8	9	10					

R: Rating OT: Observed time BT: Basic Time NT: Normal time

allowances Summary	
Personnel needs	4
Basic Fatigue	5
Variable Fatigue	
Special	
Total Allowance	**9**

Instruction for using Throughput Data Capture Sheet

This table includes two sub-tables, one sub-table would be completed at the first station of each cell, and the other one is completed at the last station of each cell. The table at the first station records the entering/start time of each car, and the other one at the last station records the departure/end time of each car.

Example:

When a car numbered 7 is entering station 11, which is the first station of cell-3 at 10:05am, one the operators at station 3 should record car-7's ID "7" into the *car number* column, and then put the time 10:05am behind the car's ID in the *time* column.

	Stop Watch Number	**11**
	Station (Entering)	**11**
	Watch Operator	**xxx**
	Car Number	**Time**
1	7	10:05

After this step, car-11 will be processed in cell-3, when it completed by the operators of station 15, the last station of cell-3, at 10:07am, one the operators should put the car ID "7" in the table, and record the completion time 10:07am.

	Stop Watch Number	**15**
	Station (Departure)	**15**
	Watch Operator	**xxxx**
	Car Number	**Time**
1	7	10:07

Instructions for using Time Study Sheet

The times recorded in this sheet include two categories, one is valid time (VA), and the other is idle time (ID). This sheet will be used at every station to determine the utilization of each station as well as the % value and none value added time for each station.

The VA time is the period while operators are working, and the ID time is the period when the operators are not working, for example, when the operators are waiting for the products come from upstream station, they are in idle period.

Example:

Car numbered “9” is entering station “3”, the operator puts “9” in the *Car Number* column, then other operator begin working on car-9, the recorder also use stop watch to record the VA time.

N.B. When an operator begins working on the first car, he will press the start button to start the clock, thereafter, the operator will press the **lap button** on the stop watch at the end of the assembly task and press the **lap button again** when he/she begin working on new subassembly. At the end of the shift the operator will press the lap button followed by stop button to finally stop time recording. Using the **Recall button** on the stop watch, the operator will record all the lap times. If no errors were made, then the odd lap times should represent the Value added times while the even lap times represent non-value added times.

When the operators completed car-9 in station-3, and they spent 60 seconds in working, the record put 60 in the time column. Please make sure this value is VA time.

	Stop watch number		3
	Station		3
	Watch Operator		xxxx
	Car Number	Time	
1	9	60	VA
2			ID

After they completed car-9, they wait 30 seconds for the other car, so the recorder put 30 in the time column too. Please make sure it belongs to the ID time.

	Stop watch number		3
	Station		3
	Watch Operator		xxxx
	Car Number	Time	
1	9	60	VA
2	9	30	ID

Throughput Data Capture Table

	Stop Watch Number:	
	Station (Entering):	Station 6
	Watch Operator:	Taylor Owens

	Car Number	Time			Car Number	Time
1	94	10:44.35		28		
2	93	10:46.05		29		
3	95	10:47.25		30		
4	90	10:48.26		31		
5	84	10:49:25		32		
6	89	10:50.50		33		
7	85	10:52.20		34		
8	96	10:53.42		35		
9	81	10:55.25		36		
10	101	10:57,05		37		
11	92	10:58.30		38		
12	97	10:59.40		39		
13	86	11:00.50		40		
14	82	11:02:25		41		
15	87	11:03:52		42		
16	88	11:05.26		43		
17	98	11:06.40		44		
18	91	11:07.50		45		
19	83	11:09.09		46		
20	80	11:10.28		47		
21	102	11:11.40		48		
22	99	11:12.50		49		
23				50		
24				51		
25				52		
26				53		
27				54		

Figure C.1: throughput Data capture sheet

Value added/Non value added analysis

	Stop watch number:	13			
	Station:	7			
	Watch Operator:	Riley Stevens			

Laps	Time		Laps	Time	
1	1:23	VA	31	1:03.12	VA
2	:07.22sec	ID	32	:01.09	ID
3	1:55	VA	33	1:34.65	VA
4	:04.15sec	ID	34	:01.22	ID
5	1:47	VA	35	1:32.66	VA
6	:03.33sec	ID	36	:01.34	ID
7	1:56	VA	37	1:35.17	VA
8	:04.51	ID	38	:01.31	ID
9	1:13	VA	39	:57.69	VA
10	:03.8	ID	40	:01.06	ID
11	:59.31	VA	41	1:03.13	VA
12	:01.02	ID	42	:01.52	ID
13	1:05.55	VA	43	1:22.52	VA
14	:01.33	ID	44		ID
15	1:46.41	VA	45		VA
16	:01.22	ID	46		ID
17	1:55.60	VA	47		VA
18	:01.59	ID	48		ID
19	1:27.29	VA	49		VA
20	:01.52	ID	50		ID
21	1:01.85	VA	51		VA
22	:01.39	ID	52		ID
23	:56.76	VA	53		VA
24	:01.44	ID	54		ID
25	1:43.46	VA	55		VA
26	:01.45	ID	56		ID
27	1:35.63	VA	57		VA
28	:01.43	ID	58		ID
29	1:04.56	VA	59		VA
30	:01.56	ID	60		ID

Figure C.2: Established value added and Non- value added times

Table C.1: Value added/ Non- value added excel template

Stop watch number						
Station	**6**					
Watch Operator	**David N.**					
Lap Number	**Time (sec)**	**St**		**Lap Number**	**Time (sec)**	**St**
1	100.6	**VA**	39	**31**	72.3	**VA**
2	2	ID	5	32	2.2	ID
3	76.2	**VA**	41	**33**	67.7	**VA**
4	21.9	ID	10	34	1.9	ID
5	62.4	**VA**	43	**35**	87.6	**VA**
6	20	ID	15	36	2.4	ID
7	75.6	**VA**	45	**37**	66.8	**VA**
8	11.7	ID	46	38	5.2	ID
9	80.6	**VA**	47	**39**	73.5	**VA**
10	3.1	ID	48	40	2.4	ID
11	88.6	**VA**	49	**41**	51.9	**VA**
12	3.9	ID	50	42	17.7	VA
13	73.3	**VA**	51	**43**	71	**ID**
14	11	ID	52	44		VA
15	80.4	**VA**	53	**45**		**ID**
16	4.6	ID	54	46		VA
17	81.6	**VA**	55	**47**		**ID**
18	2.6	ID	56	48		VA
19	81.5	**VA**	57	**49**		**ID**
20	11.5	ID	58	50		VA
21	70.6	**VA**	59	**51**		**ID**
22	2.8	ID	60	52		VA
23	76.3	**VA**	61	**53**		**VA**
24	5.2	ID	62	54		ID
25	66.5	**VA**	63	**55**		**VA**
26	24.8	ID	64	56		ID
27	68.7	**VA**	65	**57**		**VA**
28	4.1	ID	66	58		ID
29	75.5	**VA**	67	**59**		**VA**
30	10.6	ID	68	60		ID
Average value added time		77.22667		Average value added time		62.5
Average Non-value added time		9.32		Average Non-value added time		14.18333
Average value added time		**72.77**				
Average Non-value added time		**11.75**			7.043840439	

Appendix D

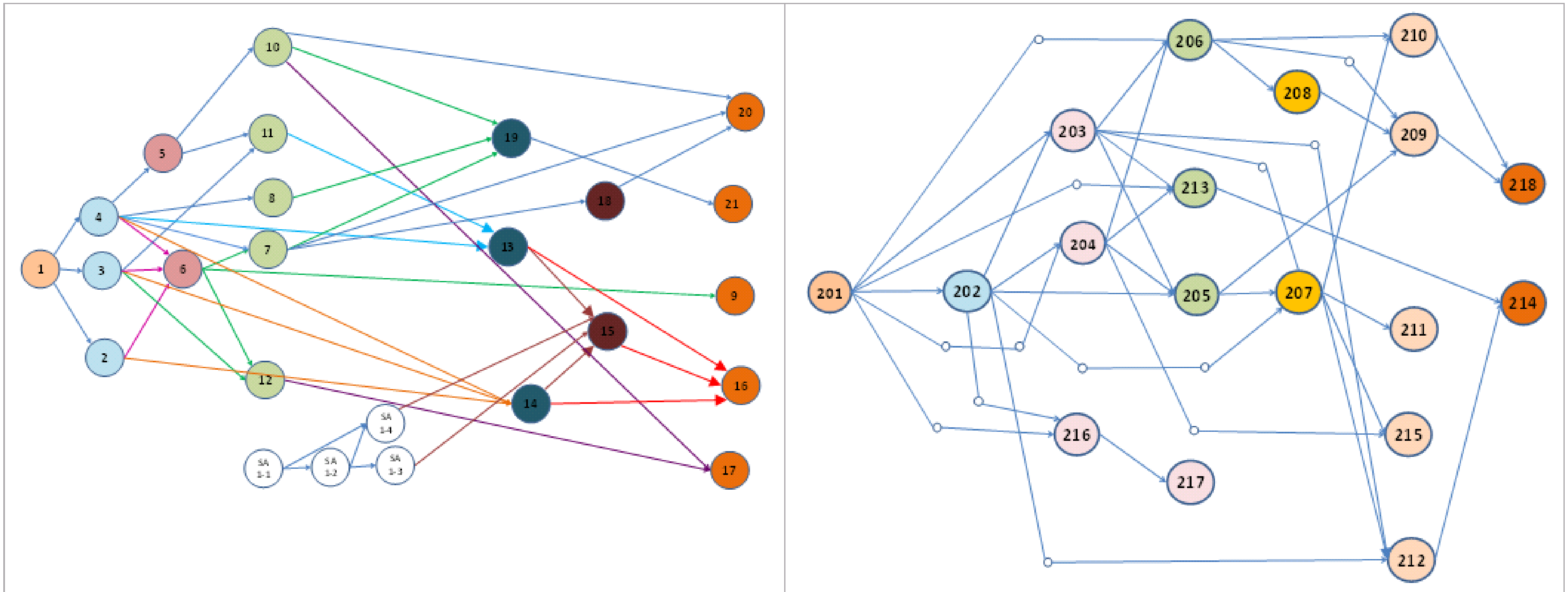
Line Balancing solutions Using Excel spreadsheet template

D.1 Cell 1 Line Line balancing solution

Cell 1: Speeder Precedance Table								
Ope # (T_{ek})	Work element Description	Serial #	Part #	Quntity	Tek(seconds)	Must be Preceded by Operation #	Station	Station Cycle Time (s)
1	place the two parts side by side	244526	73	2		-	1	
2	Assembly part as shown in in 2	4124067	54	2		1		
3	Assembly part as shown in in 3	383221	40	1		1		
		4506961	41	1				
4	Assembly part as shown in in 4	303226	71	2		1		
5	Flip Assembly and attach parts as shown in	4211445	85	1		4		
		447721	38	1				
6	Assembly part as shown in in 6	300401	2	1		2,3,4		
		302221	34	1				
		244526	73	1				
7	Assembly part as shown in in 7	4157223	16	2		4,6		
		4211445	85	1				
8	Assembly part as shown in in 8	4211529	82	2		4		
9	Assembly part as shown in in 9	4205058	83	1		6	2	
10	Assembly part as shown in in 10	300421	51	2		3		
		362226	13	2				
		4205058	17	2				
11	Assembly part as shown in in 11	4210631	91	1		3,4,5		
		307026	30	2				
		302321	64	2				
		243126	65	2				
12	Assembly part as shown in in 12	4528357	51	1		3,6		
		300421	13	1				
		621521	17	1				
13	Assembly part as shown in in 13	4157223	16	1		4,11	3	
		4211060	90	1				
14	Assembly part as shown in in 14	306201	10	4		2,3,4		
		245821	14	2				
		362221	15	3				
SA-1-1	Prep Subassembly as shown in SA-1-1	383221	40	1		-		
		306201	10	1				
		4121934	27	1				
		4211445	85	1				
SA-1-2	Prep Subassembly as shown in SA-1-2	371026	68	1		SA-1-1		
		3000840	52	2				
SA-1-3	Prep Subassembly as shown in SA-1-3	4210631	95	2		SA-1-2		
		4251162	20	2				
SA-1-4	Prep Subassembly as shown in SA-1-4	243221	21	2		SA-1-1,SA-1-2		
		3000840	45	2				
15	Attach bumper to 14	frt-bumper		1		13,14		
16	Assembly parts as shown	4124067	56	2		13,14,15	4	
		4243819	70	1				
17	Assembly parts as shown	302326	59	2		12,13		
		4227684	63	2				
18-SA	Prepare Sub Assembly	346026	69	1		-		
		4161329	43	1				
		4160866	44	1				
		4504379	26	4				
		4211527	89	4				
		302221	34	1				
		243121	23	1				
18	Attach rear bumper	ar-bumper SA		1		7		
19	Assembly part as shown in 19	302226	74	1		6,7,8,10	5	
		303426	72	2				
20	Assembly part as shown in 20	302326	59	2		7,10,18		
		362326	67	2				
		302226	74	2				
21	Assembly part as shown in 21	486526	81	3		19		
		4211549	84	1				
		Total		**96**				

Cell 1: SUV Prcecedence table

Ope # (T_{ek})	Work element Description	Part Number	Serial Number	Quantity	T_{ek} (seconds)	Must be Preceded by	Station	Station Cycle Time (s)
201	Place the two parts side by side	73	24526	2		-		
		40	24526	1		201		
202	Assembly part as shown in in 202	73	383221	1				
203	Assembly part as shown in in 203	40	383221	1		201, 202		
204	Assembly part as shown in in 204	36	303226	2		201, 202	1	
		37	371021	2		201, 202, 203, 204		
205	Assembly part as shown in in 205	13	300421	2				
		16	4157223	1				
		10	306201	4		202 ,203, 204		
206	Assembly part as shown in in 206	89	421525	4				
207	Assembly part as shown in in 207	71	303226	2		202, 203, 205		
8-SA-1	Assembly part as shown in in 208-SA-1	68	371026	1		-		
		43	4161329	1		208-SA-1		
8-SA-2	Assembly part as shown in in 208-SA-2	44	4160866	1				
		23	243121	1				
		93	3000841	2		208-SA-2	2	
8-SA-3	Assembly part as shown in in 208-SA-3	94	4542673	2				
208	Assembly part as shown in in 208		Rear bumper SA	1		206		
		74	302226	2		205, 206, 208		
209	Assembly part as shown in in 209	72	303426	1				
		23	243121	2				
		50	4205058	1		206, 207	3	
		51	4528357	1				
210	Assembly part as shown in in 210	28	366021	2				
		50	4205058	1		207		
211	Assembly part as shown in in 211	49	4179833	4				
		85	4211445	2		204,207		
215	Assembly part as shown in in 215	54	4124067	2				
		28	366021	4		201, 202	4	
216	Assembly part as shown in in 216	14	245821	4				
217	Assembly part as shown in in 217	54	4124067	4		216		
		13	300421	2				
		12	4558886	2		202, 203, 207		
212	Assembly part as shown in in 212	26	4504379	2				
		16	4157223	1		202, 203, 204		
213	Assembly part as shown in in 213	83	4211385	1				
		36	302121	2			5	
		8	366601	1		212, 213		
214	Assembly part as shown in in 214	24	416221	1				
		70	4243819	1				
		69	346026	1		207, 209, 210		
218	Assembly part as shown in in 218	52	4159553	2				
			Total	**77**				



A: Cell-1 speeder Precedence diagram	B: SUV Cell-1 SUV precedence diagram

Figure D.1: Cell 1 Precedence diagrams

	Tek (sec)	OP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	RPW
			RPW Values sorted in Descending Order																					
1	**3.90**	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	317
2	**6.52**	4	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	295
3	**8.28**	3	0	0	0	0	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	245
4	**9.06**	2	0	0	0	0	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	220
5	**8.50**	5	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	1	1	0	1	1	1	189
6	**12.89**	6	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	1	1	1	133
7	**19.60**	11	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	107
8	**8.81**	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	87
9	**65.86**	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	78
10	**15.80**	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	74
11	**10.09**	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	71
12	**36.92**	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37
13	**19.16**	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	32
14	**5.73**	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	30
15	**11.56**	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	24
16	**11.06**	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	23
17	**22.42**	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
18	**12.65**	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
19	**12.40**	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
20	**11.76**	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
21	**3.61**	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	316.58																							

Takt time (sec)	**70**
Ideal Cycle (sec)	**63.3**
Set Cycletime (sec)	**65**
Allowable variance	**-5**

Assigment of Operations to Work-Stations

Station (j)	Op (k)	RPW	Immediate predecessor	T_{ek}	Cumulative time (sec)	Unassigned time (sec)	Remarks
1	1	316.6	-	3.90	4	66	
1	4	295.3	1	6.52	10.5	59	
1	3	244.7	1	8.28	18.8	51	
	4	295.3	1	6.52	25.3	45	
	5	189.4	4	8.50	33.8	36	
	6	133	2,3,4	12.89	46.7	23	
	11	106.7	3,4,5	19.60	**66.3**	4	
2	7	71.22	4,6	10.09	10.1	60	
2	8	29.94	4	5.73	15.8	54	
2	9	3.61	6	3.61	19.4	51	
2	10	74.19	3	15.80	35.2	35	
2	13	87.07	4,11	8.81	44	26	
2	14	31.81	2,3,4	19.16	**63.2**	7	
3	15	78.26	13,14	65.86	**65.9**	4	
4	12	22.82	3,6	11.06	11.1	59	
4	18	36.92	7	36.92	48	22	
4	19	24.21	6,7,8,10	11.56	**59.5**	10	
5	16	12.4	13,14,15	12.40	12.4	58	
5	17	11.76	12,13	11.76	24.2	46	
5	20	22.42	7,10,18	22.42	46.6	23	
5	21	12.65	19	12.65	**59.2**	11	
			T_{WC}	**314**			

E_b= **0.947** **Where $E_{B\ i}$s the balance efficiency of the line**

Ed= **0.053** **Where Ed is the balance delay**

Takt Time	**70**	Sort table in desceding order of RPW
Cycle time	**65**	

	Ti (s)	OP	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	RPW
1	**5.57**	201	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	266
2	**7.55**	202	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	260
3	**6.62**	203	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	188
4	**6.64**	204	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1	0	0	1	180
5	**10.99**	205	0	0	0	0	0	0	1	0	1	1	1	1	0	1	1	0	0	1	136
6	**8.62**	207	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	100
7	**30.34**	206	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	99
8	**28.04**	216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	41
9	**25.48**	212	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	39
10	**20.83**	210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	35
11	**24.87**	208	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	33
12	**7.22**	213	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	21
13	**17.34**	215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
14	**16.73**	211	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
15	**14.27**	218	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
16	**13.60**	214	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
17	**12.75**	217	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
18	**8.20**	209	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
T_{wc}	**266**																				

TAKT TIME		**70**	This time is dependent on Customer Demand
Te(ideal)		**53.1**	This is the time time at each station needed to meet perfect balance
Cycle time		**60**	This is time
Variance		**-10**	

Assigment of Operations to Work-Stations

Station (j)	Op (i)	RPW	Immediate predecessor	T_{ij}	Cumulative	Unassigned	Remarks
1	201	266	-	5.57	4	56	
1	202	260	201	7.55	11.6	48	
1	203	188	201, 202	6.62	18.2	42	
1	204	180	201, 202	6.64	24.8	35	
1	205	136	201, 202, 203, 204	11	35.8	24	
1	207	100	202, 203, 205	8.62	44.4	16	
1	213	20.8	202, 203, 204	7.22	51.6	8	
2	206	98.5	202 ,203, 204	30.3	30.3	30	
2	216	40.8	201, 202	28	58.4	2	
3	212	39.1	202, 203, 207	25.5	**25.5**	35	
	210		206, 207	20.8	**46.3**	14	
	215		204,207	17.3	**63.7**	-4	
4	208	33.1	206	24.9	24.9	35	
4	211	16.7	207	16.7	41.6	18	
4	218	14.3	207, 209, 210	14.3	**55.9**	4	
5	214	13.6	212, 213	13.6	13.6	46	
5	217	12.8	216	12.8	26.4	34	
5	209	8.2	205, 206, 208	8.2	34.6	25	
				266			

E_b= 0.835 Where $E_{B\,i}$s the balance efficiency of the line

Ed= 0.165 Where Ed is the balance delay

Cell 2-Precedance Table

No (T_{ek})	Work element Description	Serial Number	Part Number	Quantity	Tek(sec)	Must be Preceded by	Station	Station Cycle Time (s)
22	Assembly part as shown in 22	4124096	61	2		19		
		4210631	91	2				
		4211469	88	2				
		4211525	89	4				
23	Assemby part as shown in 23	4124096	61	2		9, 20	6	71
		4528357	51	2				
		4210631	91	2				
		4211469	88	2				
		4211525	89	4				
24	Assembly part as shown in in 24	4179833	49	2		19,20		
		300421	13	2				
		4558886	12	2				
		3000841	93	2				
25	Assembly part as shown in 25	366021	28	4		20		
		4542673	94	2				
		4558886	12	2				
26	Assembly part as shown in in 26	303421	39	2		25		
27	Assembly as shown in 27	302121	35	2		26	7	91
		4160886	44	1				
		4161329	43	1				
28	Assembly parts as shown in 28	4179833	49	2		24,27		
		4504379	26	4				
		4540386	92	2				
29-SA-1	Assembly parts as shown in 29-SA-1	300901	3	1		-		
		366601	8	1				
29-SA-2	Assembly part as shown in 29-SA-2	4277932	55	2		29-SA-1		
29-SA-3	Attach wind screen	4129534	47	1		29-SA-2		
29-SA-4	Assembly screen reinforcements as shown in 29-SA-4	300501	1	6		29-SA-3	8	59
29-SA-5	Assmbly as shown in 29-SA-5	654101	11	2		29-SA-4		
29-SA-6	Assmbly as shown in 29-SA-6	371026	68	1		29-SA-5		
29-SA-7	Assmbly as shown in 29-SA-7	663626	66	1		29-SA-6		
29-SA-8	Assmbly as shown in 29-SA-8	4504379	26	2		29-SA-3		
		245821	14	2		29-SA-5		
29-SA-9	Assmbly as shown in 29-SA-9	393721	33	2		29-SA-2		
		393826	60	2		29-SA-2		
29-SA-10	Assmbly as shown in 29-SA-10	416221	24	1		29-SA-9		
29	Attach Rear door Assy			1		22,23, 27		
30	Assy as shown in 30	371021	37	1		26,28	9	61
		609121	18	2				
31	Assy as shown in 31	242026	57	2		30		
		302326	59	1				
32	Assy as shown in 32	4504382	77	2		31		
		243126	65	1				
33	Assy as shown in 33	3302301	7	2		12,16,17	10	59
		4211445	85	1				
		4124067	54	1				
	Tot number of parts			**80**				

Ope #	Work element Description	Part Number	Serial number	Quantity	Tek(seconds)	Must be Preceded by	Station	Station Cycle Time (s)
219	Assemby part	57	242026	2		209, 210	6	
		68	371026	2				
220	Assemby part	3	300901	1		218, 219		
		1	300501	3				
221	Assembly part	90	4211060	1		218, 219		
		16	4157223	2				
222	Assemby part	56	362226	2		218, 219		
		2	300401	1				
		1	300501	3				
223	Assembly part	27	4211934	2		222	7	
		9	4504379	8				
		26	4244362	2				
224	Assembly part	35	302121	2		209, 221, 222		
		54	4124067	1				
		13	300421	2				
		47	4129534	1				
225	Assembly parts	65	243126	1		224	8	
		59	302126	1				
		75	302326	2				
		74	302226	2				
226	Assembly parts	51	4528357	2		225		
		55	4277932	2				
		21	243221	2				
227	Assembly part	15	366021	2		223, 224, 226		
		28	362221	2				
228	Assembly part	21	302221	2		211, 214	9	
		32	4515365	2				
		64	307026	2				
		89	4211525	2				
229	Assembly part	65	243126	1		228		
		16	4157223	1				
		89	4211525	2				
		79	4153044	1				
		91	4210631	2				
230	Assembly part	59	362326	2		212, 214	10	
		88	4211469	2				
		67	302326	2				
231	Assembly part	29	302321	2		228, 230		
		65	243126	1				
		22	307021	2				
		30	408521	2				
		Tot number of parts		79				

Cell 3 Precedance Table								
No	**Work element Description**	**Serial Number**	**Part Number**	**Quntity**	**T_{ek} (seconds)**	**Must be Preceded by**	**Station**	**Station Cycle Time (s)**
34		4211525	89	2		16,33		
		408521	29	2				
		243126	65	1				
		371026	68	1				
	Assy as shown in 34	4571181	42	1				
35		4124067	54	2		17,33,34		
		4157223	16	1				
	Assy as shown in 35	4249112	5	2				
36		366021	28	4		17,31,35		
	Assemby part as shown in 36	408521	29	2				
37		4244362	46	2		17,35,36		
		4542673	94	1				
		346026	69	2				
	Assemby part as shown in 37	362326	67	1				
38		4159553	52	2		36		
	Assemby part as shown in 38	30202	36	2			11	
39		4210631	91	1		35		
		4155708	53	1				
		4153044	54	1				
	Assemby part as shown in 39	4124067	79	1				
40		303301	7	2		37		
		4225201	62	2				
	Assy part as shown in 40	4515365	32	2				
41-SA-1-5		3710121	37	1		34,36		
		4226876	31	1				
		4278359	78	1				
		302126	75	1				
		4560179	25	1				
	Assy door Sub Assy	302126	36	1			12	
42-SA-1-5		371021	37	1		34,36		
		4226876	31	1				
		4278359	78	1				
		302126	75	1				
		4560179	25	1				
	Assy door Sub Assy	302126	36	1				
42	Attach doors			1		34,36,39		
43		307021	22	2		38,40		
		243121	23	2				
	Assy parts as shown in 43	302026	76	1				
44		4504369	46	4		33,35,36,37,40,43		
		4160866	44	1				
		4161329	43	1				
	Assy parts as shown in 44	4518992	4	2			13	
45-SA		4517925	58	2		-		
		4520782	19	4				
		302326	59	1				
		4211395	86	1				
	Assy Hood as shown in 45	302021	36	1				
45	Secure hood as shown in 45	hood		1		40		
46		4211525	89	2		31,44		
	Assy part as shown in 46	4542700	48	1			14	
47		303226	71	1		40,46		
		4244362	9	2				
		408501	6	2				
	Assy parts as shown in 47	3000840	45	2				
48		4299119	87	4		47		
	Assy wheels as shown in 48	4550937	80	4			15	
		Tot Part count		**92**				

Appendix E

Assessing the effectiveness of hands-on labs through student surveys

E.1 Student perceptions on introductory manufacturing lab in enhancing student learning and interest

English

Default Question Block

Q1.

Informed Consent

Introduction

This Survey **seeks students perspective on what elements/components of the student's hands-on manufacturing lab enhanced their understanding of manufacturing related concepts taught in class. You have been selected because you participated in either manufacturing systems labs (INSY 3800) or Lean Production (INSY 3800). Your feedback is important for the development of future hands-on manufacturing labs** designed with the purpose of bridging the competency gaps of graduating manufacturing students. This study is being conducted by Yamkelani Moyo, PhD candidate under the direction of Dr. Richard Sesek, Assistant Professor in the Industrial and Systems Engineering Department. We hope to use the information you provide as input for developing a taxonomy for manufacturing education.

Procedures:

You will be asked to answer a series of questions based on your own experience as student that participated in hands-on manufacturing related laboratory activities . The questions asked will not not take more than 20 minutes to complete. Questions are designed to determine what aspects of the lab you found helpful in enhancing your learning of the concepts. In addition, you will be asked to suggest recommendations on how to improve manufacturing hands-on learning activities associated with manufacturing courses. These hands on learning activities are intended to bridge the gap between manufacturing industry desired skill-sets and Manufacturing education expected deliverables. This questionnaire will be conducted with an on-line Quartics-online survey.

Risks/Discomforts

Risks are minimal for involvement in this study. This is an anonymous survey.

Benefits

There are no direct benefits for participants. However, it is hoped that through your participation, researchers/educators will gain valuable knowledge on how to streamline manufacturing curriculum to fit the dynamic nature of today's manufacturing industry. The results of this survey together with perspectives of educators will provide valuable information required to develop an effective taxonomy for manufacturing education. This taxonomy could thus serve as basis for developing consensus guidelines for an effective manufacturing curriculum required to revamp the US manufacturing industry.

Confidentiality

All data obtained from participants will be kept confidential and will only be reported in an aggregate format (by reporting only combined results and never reporting individual ones). All questionnaires will be concealed, and no one other than then primary investigator and assistant researches listed below will have access to them. The data collected will be stored in the HIPPA-compliant, Qualtrics-secure database until it has been deleted by the primary investigator.

Compensation

There is no direct compensation, rather than the satisfaction one may get for making a contribution intended to revamp the manufacturing education and thus indirectly contribute towards revitalizing the manufacturing sector.

Participation

Participation in this research study is completely voluntary. You have the right to withdraw at anytime or refuse to participate entirely. If you desire to withdraw, please close your Internet browser and notify the principal investigator at this email: yzm00055@auburn.edu

Questions about the Research

If you have questions regarding this study, you may contact (Yamkelani Moyo,513-886-0160)

Questions about your Rights as Research Participants:

If you have questions you do not feel comfortable asking the researcher, you may contact Auburn Universities University Office of Human Subjects Research or Institutional Review by phone (334)-844-5966 or email at hsubjec@auburn.edu or IRBChiar@auburn.edu. s

Q2. **I have read, understood, and printed a copy of the above consent form and desire on my own free will to participate in this study.**

- Yes
- No

Q3. How old are you

- Above 19 years of age
- Below 19 years of age

Q4. What level are you right now in college?

- Freshman
- Sophomore
- Junior
- Senior

Q5. With respect to Career path, what aspiration do have with respect to a career in Manufacturing ?

- I Hope to Find a job in manufacturing
- I would rather work in different field other than manufacturing
- I prefer a job in service industry

Q6. If there is Particular career that you aspire to get into, What would that be?

Q7. Indicate if you have had participated internship while been a student at Auburn.

Yes

No

Q8. What type of industry(s) have you Interned in?

Q9. Employability skills are an important attribute that many manufacturing employers are interested in. Of the following identified competencies, how important/relevant do you consider these competencies are in preparing you for your future career.

	Not at all Important	Very Unimportant	Neither Important nor Unimportant	Very Important	Extremely Important
Use of Computer aided software CAD/CAM					
Knowledge of Ergonomic and Safety					
Lean Manufacturing knowledge					
Operations research and Optimization					
MRP/Inventory Control					
knowledge of manufacturing processes					
Statistical process control (SPC)					
Automation (knowledge of PLC and Robotics)					
Six Sigma knowledge					
Business knowledge skills					

Q10. Employability skills are an important attribute that many manufacturing employers are interested in. Of the following identified competencies, how important/relevant do you consider these competencies are in preparing you for your future career.

	Not at all Important	Very Unimportant	Neither Important nor Unimportant	Very Important	Extremely Important
Use of Computer aided software CAD/CAM					
Knowledge of Ergonomic and Safety					
Lean Manufacturing knowledge					
Operations research and Optimization					
MRP/Inventory Control					
knowledge of manufacturing processes					

Statistical process control (SPC)	◯	◯	◯	◯	◯
Automation (knowledge of PLC and Robotics)	◯	◯	◯	◯	◯
Six Sigma knowledge	◯	◯	◯	◯	◯
Business knowledge skills	◯	◯	◯	◯	◯

Q11. Please indicate your agreement/disagreement with the following statement. Participating in the below listed labs enhanced my understanding of taught concept than a classroom lecture alone would have.

	Strongly Agree	Agree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Disagree
Computer Number Control m(CNC)	◯	◯	◯	◯	◯
Programmable Logic Controller (PLCs)	◯	◯	◯	◯	◯
Manufacturing Planing and Control (Lego Lab)	◯	◯	◯	◯	◯
Time Study Lab	◯	◯	◯	◯	◯
Understanding of manufacturing terms e.g. Bottleneck process, throughput time, line balancing	◯	◯	◯	◯	◯

Q12. As part of lab component of INSY 3800, you were exposed to a number practical experience. Please indicate if you had any previous practical experience either during internship or any other you may have had associated with a different course.

	No prior experience	Somewhat knowledgeable	Aware of	Agree	Strongly Agree
Stop watch time study	◯	◯	◯	◯	◯
Robotics programming and automation	◯	◯	◯	◯	◯
Line Balancing	◯	◯	◯	◯	◯
Programmable logic controls (PLC)	◯	◯	◯	◯	◯
Computer Numerical Control (CNC)	◯	◯	◯	◯	◯
Predetermined time and motion studies	◯	◯	◯	◯	◯

Q13. This question seeks to determine the usefulness of labs in enhancing learning when compared to classroom learning alone. Using the scale shown below:
1: Least confident in concept learned
5: Most confident in concept learned
In your opinion how did participating in Lab improve your confidence in the concepts taught. Contrast this with the confidence you would have in concepts taught if all concepts are taught in classroom lecture alone without laboratory reinforcement.

	Participating in Labs in addition to lecture					**Participating in Lecture alone**				
	Least confident	2	3	4	Very confident	Least confident	2	3	4	Most confident

CNC Lab (Use of G codes Computer Numerical control)										
PLC lab (Inputs,Outputs,ladder logic, Timers, Counter etc)										
Stop watch time Study										
Line Balancing (Throughput time, bottleneck, Value added/None value added)										

Q14. Please indicate your agreement/disagreement with the following statement

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
I found the Lego lab to realistic representation of real life assembly plant							
I found the Lego lab a useful for learning how to work effectively in teams							
The Lego enhanced my my understanding some the theoretical concepts presented in the lecture							
Students are better to learn and remember theories, ideas and concepts when applied to real situations and when they have concrete experience of the way industry works							
Working with the ACE robotic simulator increased my confidence in the knowledge of how the real system works							
Participating in the Lego lab enabled me see how other topics (e.g. Ergonomics, human factors, Operations research can be integrated) to improves system performance							

Q15. If there is any way you feel the following labs can be improved, please indicate so in the space provided:

-Computer Numerical Control:

Q16. If there is a any way you feel the following lab can be improved please indicate so, in the space provided:

-Programmable logic controllers lab:

Q17. If there is a any way you feel the following lab can be improved pleased indicate so, in the space provided:

-Lego Manufacturing Systems lab (Lego Labs):

Q18. There are two kinds of labs, structured and unstructured. Structured involve following elaborate lab procedures (e.g. Line balancing) while unstructured tend to be open ended (PLC project). Indicate your preference between the two kinds of labs, please select the appropriate from the choices below:

- ◯ I prefer structured labs and Learn more this way
- ◯ I prefer open ended labs and Learn more this way
- ◯ A combination structured labs and open labs is good for learning

Q19. In comparison to lecture only courses, do feel labs enhance your learning ability and interest in particular subject

	strongly agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I pay more attention to labs than in lectures	◯	◯	◯	◯	◯
I tend to learn more in labs than lectures	◯	◯	◯	◯	◯
I learn better when I am part of a team	◯	◯	◯	◯	◯

Q20. This Question relates to the use of simulation software and Emulation Software:

	Strongly agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Using Robotic Emulation software enhanced my appreciation of robotic Programming:	◯	◯	◯	◯	◯
Using CNC software increased my Understanding of Computer Numerical control programming	◯	◯	◯	◯	◯

Q21. In the labs you were often required to work in groups, what would say would be an effective group size?

- 2 people
- between 2 and 4 people
- between 4 and 6 people
- between 6 and 10 people

Q22. If there is a any way you feel the following lab can be improved please indicate so in the space provided:

-Programmable logic controllers (PLC):

E.2 Student perceptions on introductory manufacturing lab in enhancing student learning and interest

Default Question Block

Q1. The Following Questions will give you an opportunity to contribute to the Development of the Auburn University Manufacturing Systems Interdisciplinary laboratory. Your honest and genuine contribution to this cause is appreciated. We hope you participate in this endeavor. You may Choose not to participate if so wish.

Q2. What level are you right now in college?

- Freshman
- Sophomore
- Junior
- Senior
- Graduate

Q3. what is your Gender

- Female
- Male

Q4. Select the appropriate age group in which you belong:

- 18-20 years
- 20-25 years
- 26-30 years
- 30-35 years
- > 35 years

Q5. With respect to Career path, what aspiration do have with respect to a career in Manufacturing ?

- I am presently working in manufacturing related job
- I Hope to Find a job in manufacturing
- I would rather work in different field other than manufacturing
- I prefer a job in service industry

Q6. If there is Particular career that you aspire to get into, What would that be?

Q7. Select the Individual Group Labs that You participated in:

- ◯ Value stream Mapping
- ◯ Single Minute exchange of Dies (SMED)
- ◯ Cell Design and Manning strategies
- ◯ Outreach student

Q8. Indicate to what extent your agree with the following statement:
I feel that participating in the hands-on individual Lean Production Labs helped my understanding of the following Lean concepts better than traditional classroom lecture alone would.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Understand the drawback of MRP Push systems	◯	◯	◯	◯	◯
Pull single Piece flow	◯	◯	◯	◯	◯
Heijunka (Load leveling)	◯	◯	◯	◯	◯
2 card Kanban production flow control	◯	◯	◯	◯	◯
Use of Super Markets	◯	◯	◯	◯	◯
Single minute exchange of dies	◯	◯	◯	◯	◯
Kaizen (Continuous improvement)	◯	◯	◯	◯	◯

Q9. From experience with the Lean Production Course you just participated in. Provide a perspective as to how necessary it is to include the following hands-on activities to supplement classroom lectures for deeper learning and understanding to occur.

	Not at all Important	Very Unimportant	Somewhat Unimportant	Neither Important nor Unimportant	Somewhat Important	Very Important	Extremely Important
Push(MRP, Production run 1) Vs Pull (Kanban-Production run2, and 3)	◯	◯	◯	◯	◯	◯	◯
Single Piece Flow	◯	◯	◯	◯	◯	◯	◯
Heijunka (Load leveling)	◯	◯	◯	◯	◯	◯	◯
2 card Kanban production control	◯	◯	◯	◯	◯	◯	◯
Use of Super Markets	◯	◯	◯	◯	◯	◯	◯
Single Minute exchange of Dies(SMED)	◯	◯	◯	◯	◯	◯	◯
Kaizen (Continuous improvement)	◯	◯	◯	◯	◯	◯	◯

Q10.
From following list of hands-on activities associated with the Lean Production course, rank each according to which offered you the best learning experience with regards to enhancing your understanding of Lean manufacturing concepts, using the scale shown below

1-Least learning experience 8- Best learning experience :

- [ ] Push(MRP, Production run 1) Vs Pull (Kanban-Production run2, and 3)
- [ ] Single Piece Flow
- [ ] Heijunka (Load leveling)
- [ ] 2 card Kanban production control
- [ ] Use of Super Markets
- [ ] Single Minute exchange of Dies(SMED)
- [ ] Kaizen (Continuous improvement)
- [ ] Value stream Mapping

Q11. Team Work

Using the Scale provided indicate to what extent you agree with the following statement regarding the lab:

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
I feel working in team enhances my learning experience	◯	◯	◯	◯	◯	◯	◯
My participation as a team member was a good experience on how to work in a team	◯	◯	◯	◯	◯	◯	◯
I was generally Happy with level of participation and contribution of my team members	◯	◯	◯	◯	◯	◯	◯
Report writing should be done in smaller groups to encourage participation	◯	◯	◯	◯	◯	◯	◯
Use of peer evaluation is necessary when working in larger groups to encourage participation.	◯	◯	◯	◯	◯	◯	◯

Q12. This Question applies only to out reach students:

Using the Scale provide indicate if you agree with the following statements:

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Watching the videos of the Live Production runs provide a good learning experience:	◯	◯	◯	◯	◯	◯	◯
I was able to follow what was happening from the Video presentation of the production runs	◯	◯	◯	◯	◯	◯	◯

Q13. **Course Composition Grade Distribution: applies only to Graduate students**
Indicate what you feel would be fair distribution of grades associated with each elements of this Class:

In Class Quizzes (currently 54%)	0
Hands-on Lab activities (currently 17%)	0
Kaizen Paper (currently 17%)	0
Book Write up (Currently 12%)	0
Total	0

Q14. What suggestions do have to improve team performance and cooperation during Lean production hands-on activities.

Q15. With respect to hands-on lean production activities and Classroom lecture indicate to what extent you agree with following statement:

	Strongly Agree	Agree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Disagree	Disagree	Strongly Disagree
I find that lean production hands-on activities enhances my interest in the Lean Production subject Matter	○	○	○	○	○	○	○
Participating in hands-on Lean manufacturing activities helped me relate theory to practice.	○	○	○	○	○	○	○
I learn better when I am part of a team	○	○	○	○	○	○	○

Q16. If there is a any way you feel the following lab can be improved please indicate so, in the space provided:

Q17. In the labs you were often required to work in groups, what would say would be an effective group size?

- 2 people
- between 2 and 4 people
- between 4 and 6 people
- between 6 and 10 people

Appendix F

Assessment through written test

F.1 Midterm exam

INSY 5800/6800/6806 – Mid Term Exam

8) From the example above, how many jobs are required given a target of 70% Utilization? (4 points)

40+15+20+15+25=115   115/.7/55=2.98 or 3 jobs

9) How do you indicate an area of focus for improvement on a future state value stream map? (2 points)
Kaizen Burst

10) If batching in one cell feeds the next cells continuous flow, how would you create a pull between the two cells? (2 points)
Supermarket or Heijunka Box

11) Select from the following choices, a statement that is not a true indicator of the purpose for creating a current value stream map. (1 point)

a) Value stream map is a tool that helps you to understand the flow of material and information as the product makes its way through the value stream.
b) Value stream is a tool for optimizing flow through the value stream
c) In any value stream map information flows should be shown to indicate how communication between a Customer and supplier takes place.
d) A Value stream can be extended to cover external operations of suppliers in any value stream.

12) Name any three pieces of Information that are critical for developing a Value Stream map (3 points)

a) ____________________________________
b) ____________________________________
c) ____________________________________

13) Which of the following inventory items in a value stream influences the overall lead time? (1 point)

a) Work In Process (WIP)
b) Raw material stock (Stock at Hand)

14) What is the best way of drawing an initial value stream map? (1 point)

a) Use of graphical software such as Power point or Micro-Soft Visio

b) Pencil and Paper

15) Indicate if the following tasks are **Value Added** or **Non Value Added** tasks. Use "**VA**" for value added and "**NVA**" for non-value added. (3 points)

a) An Operator at Station 1 in a manufacturing cell picks a part from a bin and assembles to a sub assembly:_____________

b) An operator takes one minute to inspect the part before passing it on to a downstream station:________________

c) An operator at Station 2, on realizing that an error in assembly has occurred, takes one minute to correct the problem before passing it to a downstream station:_____________

16) State whether the following statement is true or false as they relate to value stream mapping. **T/F.** (5 points)

a) Value stream Mapping should only be limited to the operations of one department in a manufacturing plant:____________

b) Information flows, showing the communication between functional areas of a plant are an integral part of value stream mapping:___________

c) Increasing the WIP between Processes and Department results in the reduction of total Lead time:______________

d) The Change Over time should be indicated on the value stream map:___________

e) The Cycle time of a particular process in the manufacturing system can be larger than the Takt time if the Customer demand is to be met:________________

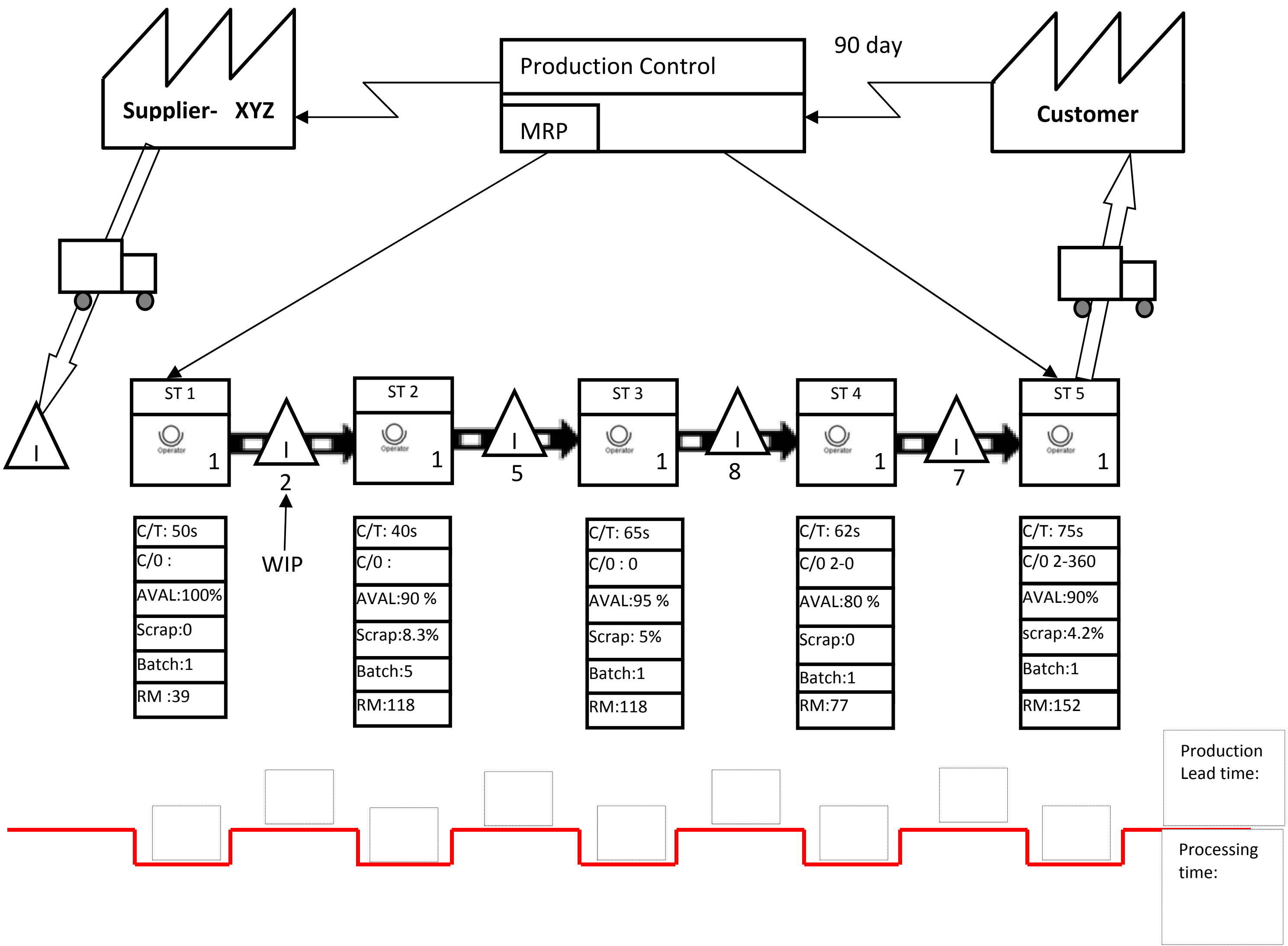
17) What is your understanding of Production Lead time as it relates to Value stream mapping: (2 points)

18) The Figure below shows a Value stream map for a 5 station manufacturing Cell used to manufacture a small toy car. Given the following information about the Manufacturing system:

Daily demand for the toy car is 460 units/day and available working time per day is 27 600 seconds/day. Using this information it can be determined that the takt time is 60 seconds. Using this information and WIP indicated below the triangle in Figure 1:

i) Fill out the cycle times and Inventory Lead times in the boxes provided on the time line in Figure 1. (9 points)

ii) Determine the Production lead time and Processing time by filling in the boxes in Figure 1. (4 points)



Key: C/T=Cycle time, C/O= change Over, RM=Raw Material inventory

Figure 1 Value stream map

F.2 Quiz 3

INSY 5800/6800 Quiz #3

8. If the process is changed to bring the process under the threshold, what factor of the Risk Priority Number does not cannot change? **(1 point)**

9. What are the two pillars of the Toyota Production System? **(2 points)**

10. What method is used to accomplish delivery of complex components to a mixed model Final Assembly line? **(2 points)**

11. What do you understand by SMED? **(2 points)**

12. Name two categories that are the basis for SMED **(2 points):**

- ________________________________
- ________________________________

Select the best answer:

13. SMED is important to Companies because it **(1 point)**

a. Helps reduces defects
b. Helps companies meet customer needs with less waste by allowing smaller lot production
c. It encourages team work among workers

14. Based on what you know on SMED, list three ways in which SMED may benefit a company. **(3 points):**

a. ____
b. ____
c. ____

15. Which of the following is the first stage of implementing SMED? **(1 point)**

a. Converting internal setup activities into External setup activities
b. Streamlining all aspects of setup operation
c. Separating external and external setup activities

INSY 5800/6800 Quiz #3

16. Answer True or False to the following statements. **(4points)**

a. A checklist can be used to determine the tools required for carrying a SMED operation. **T / F**

b. Function checks to determine if parts are in perfect working condition are an integral part of SMED. **T / F**

c. A rabbit chase is a Manning strategy used in U cells **T / F**

d. The time taken to produce a new part and checking it after changeover process s is considered as part of the total changeover time **T / F.**

17. Give three advantages of Operating a U shaped Cell as opposed to the traditional straight line (**3 points)**.

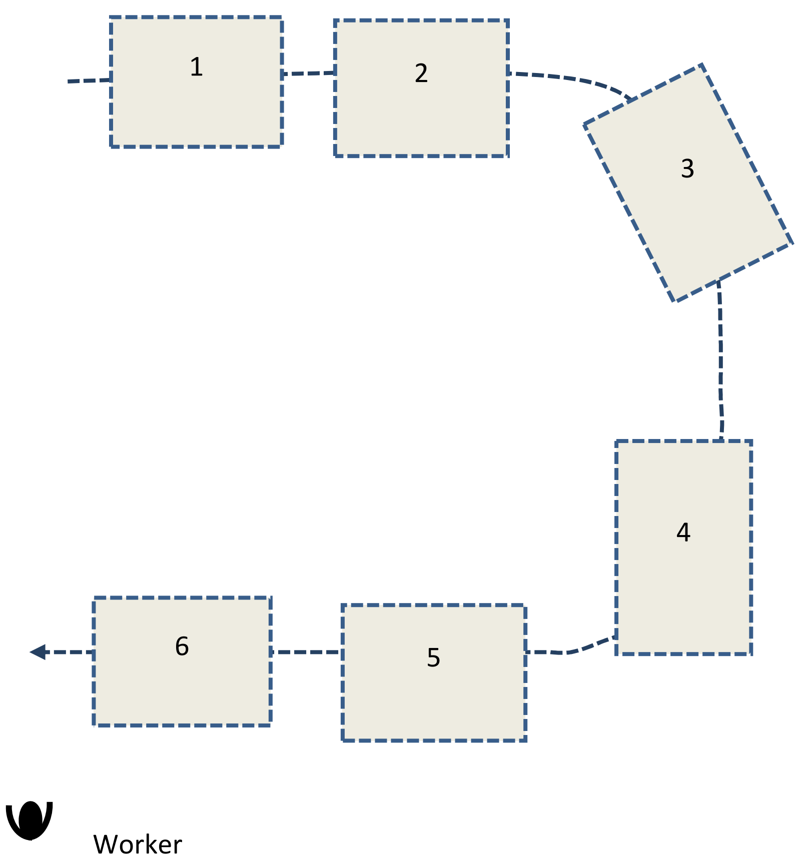
a. ____

b. ____

c. ____

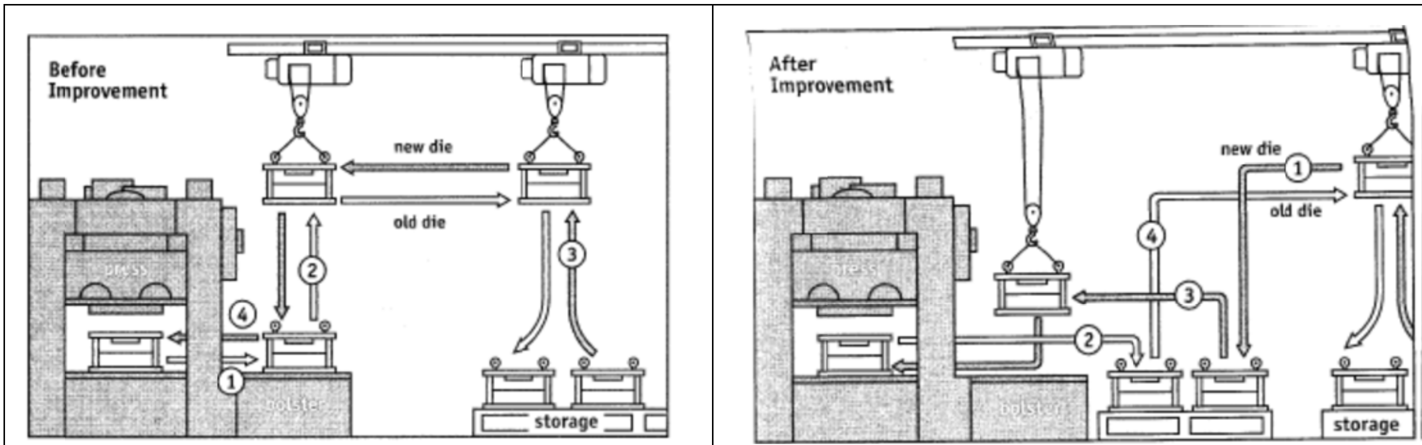
18. Suppose that you have U shaped Cell with six stations as shown below. At peak demand, the Cell is manned with 6 workers. Suppose that demand for the product dropped to a 1/3. State the number of workers you would require to run the Cell and the manning strategy you would employ. Illustrate the movement of each worker in cell in using arrows in the figure below **(3 points).**

a. Number of Workers required________________________



INSY 5800/6800 Quiz #3

19. The Figure below illustrates a SMED improvement at Y industries. **(5 points)**



Before Improvement:

1. After the machine is stopped, old die is extracted from machine onto a moving bolster.
2. A crane hoist the old die from the moving bolster and carries it to the storage area
3. A crane then hoist the new die from the storage area and transports it to the moving bolster
4. The new die is mounted and machine started again for production

After Improvement:

1. Before the machine was shut down, the crane brought the new die and placed it next to the machine.
2. The machine finished the previous operation and was stopped. The old die was removed onto the moving bolster. The crane hoisted the old die from the bolster, and then set it down near the machine.
3. Next the crane hoisted the new die onto the moving bolster. The new die was mounted and the machine started up.
4. After the machine began the new operation, the crane hoisted the old die and returned it to the storage area.

The changeover process illustrated above shows the before and after improvement scenarios. The numbered circles indicate the activities done to accomplish the changeover process. Indicate with (I: internal, E: external) in what category each of the activities for the before/after improvement scenarios fall into. Also, give a logical estimate of the time taken for an activity in the "Time taken column".

Complete the table below:

Before Improvement			After Improvement		
Activity #	Internal/External	Time taken (sec)	Activity #	Internal/External	Time taken (sec)
1		60	1		
2		120	2		
3		120	3		
4		60	4		

Appendix G

Computer simulation results for Tiger Motors shop floor

Tiger Motors push MRP productions strategy

Change over time		**60 sec**
Batch size	**SP**	**3**
	SUV	**2**
Supermarket size		**N/A**

Object ...	Object ...	Data Source	Category	Data Item	Statistic	Average Total
Model	Model	Lateness	UserSpecified	RecordedValue	Average (Minutes)	11.4389
					Maximum (Minutes)	26.7559
					Minimum (Minutes)	0.3847
					Observations	100.0000
		Cell_3_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	6.0920
					Maximum (Minutes)	9.3143
					Minimum (Minutes)	1.1534
					Observations	100.0000
		Cell_3_Throughput	UserSpecified	RecordedValue	Average	50.5000
					Maximum	100.0000
					Minimum	1.0000
					Observations	100.0000
		Cell_2_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	7.5699
					Maximum (Minutes)	15.0745
					Minimum (Minutes)	0.0000
					Observations	105.0000
		Cell_2_Throughput	UserSpecified	RecordedValue	Average	45.2667
					Maximum	97.0000
					Minimum	0.0000
					Observations	105.0000
		Cell_1_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	16.8566
					Maximum (Minutes)	32.0072
					Minimum (Minutes)	0.0000
					Observations	101.0000
		Cell_1_Throughput	UserSpecified	RecordedValue	Average	42.7800
					Maximum	92.0000
					Minimum	0.0000
					Observations	100.0000

Tiger Motors push MRP productions strategy

Change Over time		**300**
Batch size	**SP**	**3**
	SUV	**2**
Supermarket size		**N/A**

Object ...	Object ...	Data Source	Category	Data Item	Statistic	Average Total
Model	Model	Lateness	UserSpecified	RecordedValue	Average (Minutes)	22.3812
					Maximum (Minutes)	68.2892
					Minimum (Minutes)	0.3847
					Observations	59.0000
		Cell_3_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	5.4162
					Maximum (Minutes)	7.9037
					Minimum (Minutes)	1.1534
					Observations	59.0000
		Cell_3_Throughput	UserSpecified	RecordedValue	Average	30.0000
					Maximum	59.0000
					Minimum	1.0000
					Observations	59.0000
		Cell_2_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	6.7580
					Maximum (Minutes)	14.6834
					Minimum (Minutes)	0.0000
					Observations	58.0000
		Cell_2_Throughput	UserSpecified	RecordedValue	Average	21.9828
					Maximum	50.0000
					Minimum	0.0000
					Observations	58.0000
		Cell_1_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	35.1148
					Maximum (Minutes)	81.5619
					Minimum (Minutes)	0.0000
					Observations	52.0000
		Cell_1_Throughput	UserSpecified	RecordedValue	Average	18.5490
					Maximum	43.0000
					Minimum	0.0000
					Observations	51.0000

Tiger Motors push MRP productions strategy

Change over time		**300 sec**
Batch size	**SP**	**9**
	SUV	**6**
Supermarket size		**N/A**

Object ...	Object ...	Data Source	Category	Data Item	Statistic	Average Total
Model	Model	Lateness	UserSpecified	RecordedValue	Average (Minutes)	14.3423
					Maximum (Minutes)	35.8010
					Minimum (Minutes)	0.3847
					Observations	93.0000
		Cell_3_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	5.2802
					Maximum (Minutes)	7.7852
					Minimum (Minutes)	1.1534
					Observations	93.0000
		Cell_3_Throughput	UserSpecified	RecordedValue	Average	47.0000
					Maximum	93.0000
					Minimum	1.0000
					Observations	93.0000
		Cell_2_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	7.5678
					Maximum (Minutes)	14.2786
					Minimum (Minutes)	0.0000
					Observations	96.0000
		Cell_2_Throughput	UserSpecified	RecordedValue	Average	40.7917
					Maximum	88.0000
					Minimum	0.0000
					Observations	96.0000
		Cell_1_Throughput_Time	UserSpecified	RecordedValue	Average (Minutes)	20.2273
					Maximum (Minutes)	37.8337
					Minimum (Minutes)	0.0000
					Observations	92.0000
		Cell_1_Throughput	UserSpecified	RecordedValue	Average	38.8043
					Maximum	84.0000
					Minimum	0.0000
					Observations	92.0000

Tiger Motors Lean Pull production strategy

Change over time		**60sec**
Batch size	**SP**	**3**
	SUV	**2**
Supermarket size		**8**

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
Model	Model	Cell_1_Throughput	UserSpecified	RecordedValue	Observations	93.0000
					Minimum	0.0000
					Maximum	85.0000
					Average	39.3011
		Cell_1_Throughput_Time	UserSpecified	RecordedValue	Observations	93.0000
					Minimum (Min...	0.0000
					Maximum (Mi...	14.1705
					Average (Min...	8.3800
		Cell_2_Throughput	UserSpecified	RecordedValue	Observations	101.0000
					Minimum	0.0000
					Maximum	93.0000
					Average	43.2772
		Cell_2_Throughput_Time	UserSpecified	RecordedValue	Observations	101.0000
					Minimum (Min...	0.0000
					Maximum (Mi...	14.4971
					Average (Min...	6.7844
		Cell_3_Throughput	UserSpecified	RecordedValue	Observations	99.0000
					Minimum	1.0000
					Maximum	99.0000
					Average	50.0000
		Cell_3_Throughput_Time	UserSpecified	RecordedValue	Observations	99.0000
					Minimum (Min...	0.0000
					Maximum (Mi...	11.1907
					Average (Min...	7.2663
		Lateness	UserSpecified	RecordedValue	Observations	98.0000
					Minimum (Min...	1.0480
					Maximum (Mi...	29.6450
					Average (Min...	11.5285

Tiger Motors Lean Pull production strategy

Change over time		**300sec**
Batch size	**SP** **SUV**	**N/A**
Supermarket size		**8**

Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
Model	Model	Cell_1_Throughput	UserSpecified	RecordedValue	Observations	50.0000
					Minimum	0.0000
					Maximum	42.0000
					Average	18.0600
		Cell_1_Throughput_Time	UserSpecified	RecordedValue	Observations	50.0000
					Minimum (Min...	0.0000
					Maximum (Mi...	34.0838
					Average (Min...	17.8998
		Cell_2_Throughput	UserSpecified	RecordedValue	Observations	61.0000
					Minimum	0.0000
					Maximum	53.0000
					Average	23.4590
		Cell_2_Throughput_Time	UserSpecified	RecordedValue	Observations	61.0000
					Minimum (Min...	0.0000
					Maximum (Mi...	14.1966
					Average (Min...	5.6006
		Cell_3_Throughput	UserSpecified	RecordedValue	Observations	59.0000
					Minimum	1.0000
					Maximum	59.0000
					Average	30.0000
		Cell_3_Throughput_Time	UserSpecified	RecordedValue	Observations	59.0000
					Minimum (Min...	0.0000
					Maximum (Mi...	10.3397
					Average (Min...	5.8441
		Lateness	UserSpecified	RecordedValue	Observations	59.0000
					Minimum (Min...	1.0480
					Maximum (Mi...	62.6977
					Average (Min...	19.9407